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VEHICLE RESEARCH AND TEST CENTER

HYBRID III NECK HYPER EXTENSION DETERMINATION

Roger A. Saul, Project Engineer
Brian Tanner, TRC Research Engineer
Thomas F. MacLaughlin, Project Manager

1.0 BACKGROUND

The NHTSA Docket #74-14; Notice 39 had proposed several MVSS 208 injury criteria, including a requirement to address neck injuries caused by hyperextension. When the final rule was issued in Notice 45, the neck injury criterion was not included. However, the notice stated that a Supplemental Notice of Proposed Rule Making would be issued to include requirements for neck measurements.

The proposed neck requirements were based on the work of Mertz and Patrick (1). Their work showed that tolerance levels based on the torque developed at the occipital condyles had better correlation with neck injuries than tolerances based on shear or axial forces. They estimated that ligamentous injuries are likely for a 50th percentile male when occipital moments exceed 57 N*m during hyperextension of the neck.

Application of the Mertz and Patrick tolerance levels required the determination of head angular position. The use of high-speed films, however, has not been considered an objective means for measuring head position for Motor Vehicle Safety Standards testing. An earlier attempt to determine the angular position of the head suggested that negative occipital shear forces exceeding 222 N were indicative of the hyperextended condition (2). A more extensive examination of that hypothesis, however, showed that several loading conditions were capable of generating such shear forces without producing hyperextension of the neck (3).

The development of a lower neck load transducer for the Hybrid III offered other potential methods to determine head angular position. Lower neck force and moment measurements were examined for a correlation with head angular positions. In addition, rugged angular velocimeters which utilize magnetohydrodynamic principles have recently been developed. These sensors may permit objective measurement of head angular position while requiring only moderate data processing. This report summarizes the results of analyses of both these devices.

2.0 LOWER NECK LOAD TRANSDUCER

2.1 Approach

Existing data from six tests were selected for this analysis. All of the tests had been conducted with a Hybrid III head/neck assembly complete with both upper and lower neck instrumentation. Some of the tests were full dummy tests while others were component level tests. The tests shown in Table 1 were chosen because they represented a wide range of loading conditions and included some record of the angular head excursion. Appendix A contains brief descriptions of the protocol for the tests listed in Table 1.

As Table 1 shows, the angular head excursions were obtained either from high-speed film analysis or measured directly with a two rotary potentiometer/linkage device (Figure 1). The data from the head/neck pendulum tests were only available as plots in the test report (4). The graphic data was converted to digital data with a time base of 4000 points/second through the use of digitizing software with an automatic cubic spline interpolation feature. In order to facilitate presentation of the data in this report, the time bases of data from the other tests were converted to the same 4000 points/second. In most cases, this was accomplished by sub-sampling existing data. However, cubic spline interpolation was also used to add points to the head position data from the HYGE sled tests, which were created through digitization of the photographic data.

TABLE 1

PROJECT#	TEST#	DESCRIPTION	ANGULAR POSITION RECORD	REFERENCE
SRL-59	76NF 01	Head/Neck Calibration Pendulum (Flexion)	rotary pot.	(4)
SRL-59	76NE 01-03	Head/Neck Calibration Pendulum (Extension)	rotary pot.	(4)
86-0034	LIN45 01-05	Linear Pendulum Forehead Impact (Head/Neck Only)	rotary pot.	(3)
87-0078	P1M315, P1M316	HYGE Sled Crash Simulation (2-Point Automatic Restraint)	film	(5)
87-0078	P2M111	HYGE Sled Crash Simulation (Airbag Restraint)	film	(6)
86-0030	581	HYGE Sled Crash Simulation (Unrestrained Front Header Impact)	film	(7)

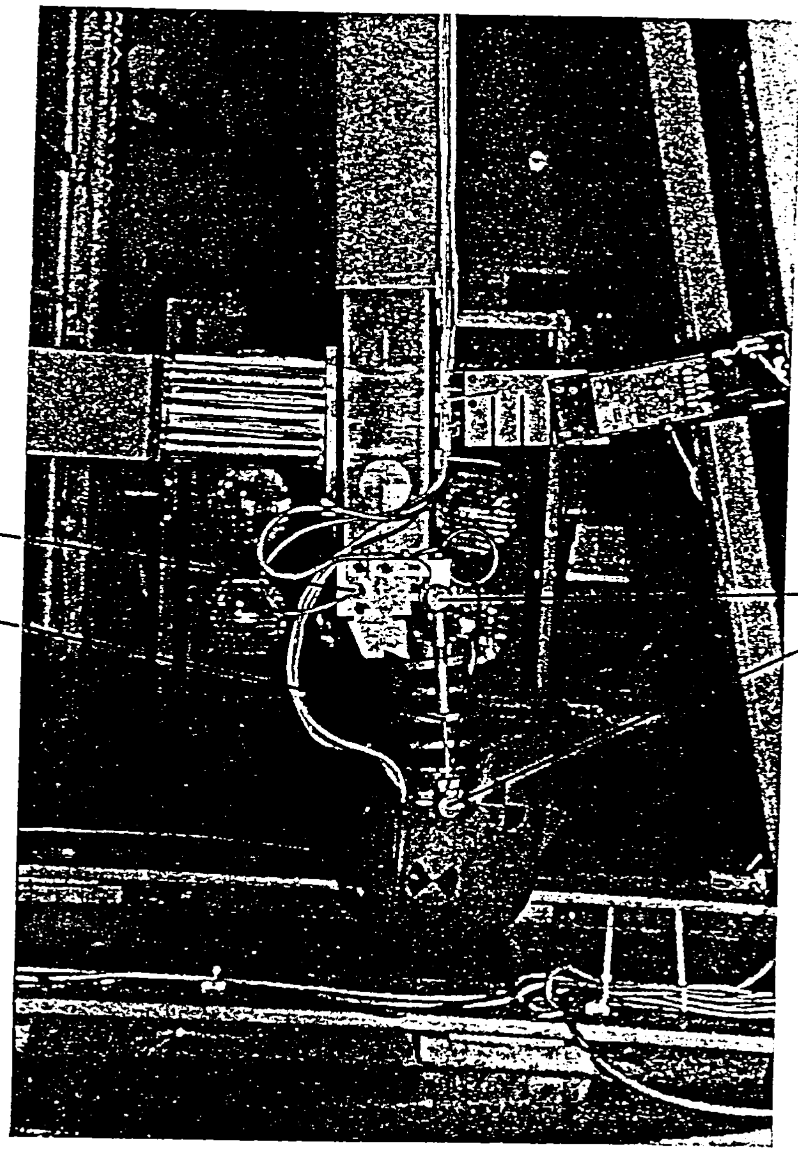


FIGURE 1 - Dummy Neck Pendulum Extension Test Setup Showing the Neck Bracket Mounted MHD Sensor and the 2-Rotary Potentiometer Device for Measuring Neck Rotation

These data were examined for some correlation between hyperextension of the neck and the measured neck forces. Hyperextension, in this report, refers to rearward rotation of the head of greater than approximately 80 degrees with respect to the torso (8). This number is not stated precisely because the limited biomechanical data cannot completely overcome the variability among biological specimens.

As earlier attempts to correlate upper neck forces had not been successful, this analysis concentrated on lower neck force and moment measurements. Additionally, the examination was limited to a two dimensional analysis, considering only the X-and Z-forces and the moments about the Y-axis. The sign convention for these forces and for the other forces measured by the lower neck load cell are listed in Table 2. It was considered unlikely that Y-forces or moments about the X- or Z-axes contributed to extension and hyperextension of the neck. Force/angle and moment/angle relationships were scrutinized for patterns that were consistent for all of the various loading mechanisms. Several quantities derived from the force and moment measurements were also examined.

2.2 Results

Three different parameters were examined in an attempt to find a correlation between a lower neck measurement and the angle of the neck extension. Both the torque about the Y-axis and the X-axis shear force were examined, but no correlations were observed for either measurement. The angular impulse about the base of the neck was also calculated using the lower neck moment measurement,

TABLE 2*

Positive Coordinate for Neck Load Cells

TYPE	AXIS	LOAD FOR POSITIVE RESPONSE
Frontal Shear (fore/aft)	X	Push back of head forward while holding thorax
Lateral Shear (left/right)	Y	Push at bottom of occupant's head on right side toward left while holding thorax
Axial Tension	Z	Head pulled relative to neck
Moment	X	Push top of head toward right shoulder
Moment	Y	Flexion (push chin toward the chest, head nodding yes)
Moment	Z	Push chin toward occupant's left shoulder (head nodding no)

*Table from (10)

but again no correlation was found.

The unrestrained front header impact tests included a nine accelerometer array giving an opportunity to measure the dummy head rotation by double integration of the angular acceleration. Results were found to be in good agreement with the film analysis of head rotation. The thought then followed that direct measurement of head rotation might be possible for application of the Mertz neck tolerance criterion.

3.0 ANGULAR VELOCITY SENSOR

Laughlin (9) has reported on the development of a miniature magnetohydrodynamic

(MHD) rotational velocity sensor. By using two of these sensors - one placed in the dummy head, and one in the dummy torso - the relative rotation could be determined from the difference of the integrated sensor signals. The following section describes testing conducted to evaluate the potential application of the MHD sensors to the neck extension injury criterion.

3.1 Approach

To analyze the suitability of this device for measuring head angular positions in crash simulations, seven types of tests were performed. These tests were similar to those discussed in the first part of this report. Once again, a series of pendulum head/neck flexion and extension calibration tests were performed. Also, a set of linear pendulum forehead impact tests were carried out and four sled crash simulations, each examining different occupant/restraint combinations, were performed. These tests are summarized in Table 3, and a more complete description is given in Appendix A. In the pendulum tests, angular velocity sensors were placed in the dummy heads and on the pendulum arms; in the linear impact tests, a sensor was placed in the dummy head; and in the sled tests, sensors were placed in the dummy head and the dummy torso.

The dummy head and neck used in the pendulum tests were instrumented with both the new sensors and the two rotary potentiometer linkage discussed earlier. In addition, the neck contained the upper load cell which measures neck axial load (Z), neck shear (X) and neck moment about the Y-axis. This allowed computation of the moment about the occipital condyles. Finally, high-speed film records were made of all tests. The angle of rotation was measured as described earlier with the potentiometers, and it was measured with the new sensors using the following procedure. Keeping in mind the sign convention that flexion is considered positive rotation and extension is considered negative rotation, the output from the sensor mounted on the pendulum arm, which represents the torso in this case, is subtracted from the output of the sensor in the head. This results in a curve representing the angular velocity of the head relative to the

TABLE 3

PROJECT#	TEST#'S	DESCRIPTION	ANGULAR POSITION RECORD
86-0034	V34NE 1-3	Head/Neck Calibration Pendulum (Extension)	rotary pot. & MHD* (& film--#3)
86-0034	V34NF 1-3	Head/Neck Calibration Pendulum (Flexion)	rotary pot. & MHD (& film--#1)
86-0034	V34IE 1-3	Linear Pendulum Forehead Impact (Head/Neck Only)	rotary pot. & MHD (& film--#2)
86-0034	TRC301	HYGE Sled Crash Simulation (3-Point Restraint)	MHD
86-0034	TRC302	HYGE Sled Crash Simulation (Airbag Restraint)	film & MHD
86-0034	TRC303	HYGE Sled Crash Simulation (Unrestrained Driver)	film & MHD
86-0034	TRC304	HYGE Sled Crash Simulation (Unrestrained Passenger)	MHD

*Angular Vel. Sensor

torso. This time history is then integrated to give a record of the rotation of the neck.

The instrumentation of the dummy head and neck used in the linear forehead impact tests was similar to that used in the pendulum tests. The only significant difference was that the bracket on which the head/neck assembly was mounted was not instrumented. In this case, the bracket represented the torso and was assumed to be rigidly attached to the ground. Thus, measuring the neck rotation angle using the angular velocity sensor involved direct integration of the sensor output. Using the potentiometers to measure the angle of rotation was again done as before.

The dummy used in the sled crash simulations was instrumented to output complete acceleration data from the head, chest, and pelvis. In addition, it utilized both upper and lower neck load transducers and right and left femur load cells. Finally it was equipped with the angular velocity sensors as described above. The angular rotation of the neck was determined in these tests using two angular velocity sensors as in the pendulum tests. The only significant difference was that the sensor which had been on the pendulum arm was now in the torso. High-speed film records were also made of these sled tests. It was hoped that these records could be used to confirm measurements made with the angular velocity sensors. However, because of targeting problems, only the airbag and unrestrained driver tests (TRC302 and TRC303) could be analyzed with any accuracy in this manner.

3.2 Results

Figure 2 shows the time traces of the head angular velocity and pendulum angular velocity for the first neck extension pendulum test. Although the pendulum data is somewhat noisy due to vibration of the pendulum arm, the amplitude of this noise is small compared to the total angular velocity of the head, and any integration error resulting from this noise is negligible. The Y-moment about the occipital condyles and the total neck rotation as measured by both the potentiometers and the MHD sensors are shown in figure 3 for this test. Note that the maximum amplitude of this moment is negative 52.76 N*m at approximately 75 milliseconds after loading. This is slightly less than the negative 57 N*m criteria for injury established by Mertz. Also, notice that the total neck rotation curves as developed from the potentiometers and the angular velocity sensors agree very closely in peak response.

The results of all of the pendulum flexion/extension tests were very similar. The plots of the measured Y-moment and rotation angles from these tests are given in figures B1-B5 of appendix B. In each of the plots for rotation angle, generally good agreement is seen in the peak response for both the potentiometers and the angular velocity sensors. Later in the response, greater deviations are seen. The reasons for these deviations are not clear. Integration error does not seem to be the cause, and there is no reason to suspect problems with the test setup. Film records of two of the tests, V34NE3 and V34NF1, were used to measure the rotation angle in the hope of confirming the results of either the linked potentiometer device or the angular velocity sensors. Examination of figures B2 and B3 in Appendix B shows that, while it appears slightly better agreement exists between the film and MHD data for V34NF1, this is not confirmed by the data from the other test. Given the uncertainty in the film data, neither device is shown to be more accurate.

Turning our attention to the data from the linear impactor tests, the time history of the head angular velocity from test V34IE1 is shown in figure 4 together with records of the Y-moment about the occipital condyles, and the total neck rotation. The interesting feature of the first plot is that the head is experiencing significant oscillation due to the ram acceleration before the impact occurs, indicating that the assumed rigidity of the bracket to which the head was attached is not really valid. This fact will lead to some error in the angular velocity results. Examination of the third plot in this figure, which shows neck rotation, indicates somewhat less agreement in peak response than in the pendulum tests, however results are still fairly good, and the additional difference is most likely due to the error introduced in the rigid bracket assumption.

The results of the other linear impactor tests were similar and the plots of the Y-moment about the occipital condyles and the neck rotation angles are given in figures B6 and B7 of appendix B. In these tests, it is again apparent that relatively good agreement is seen in the peak responses of the linked potentiometers and the angular velocity sensor. However, agreement becomes worse later in the record. The reason for this is again unclear, and film analysis was performed using the record of test V34IE2 to try to lend greater credence to the results of one device or the other. As the plot of neck rotation in figure B6 shows, however, the film data does not agree more closely with one device than the other. It should be noted that film analysis is subject to several errors including problems associated with representing three dimensional objects in two dimensions, problems with targets and reference points being hidden in some frames, and problems with timing precision.

Attention is now directed to the results from the sled crash simulations. Test

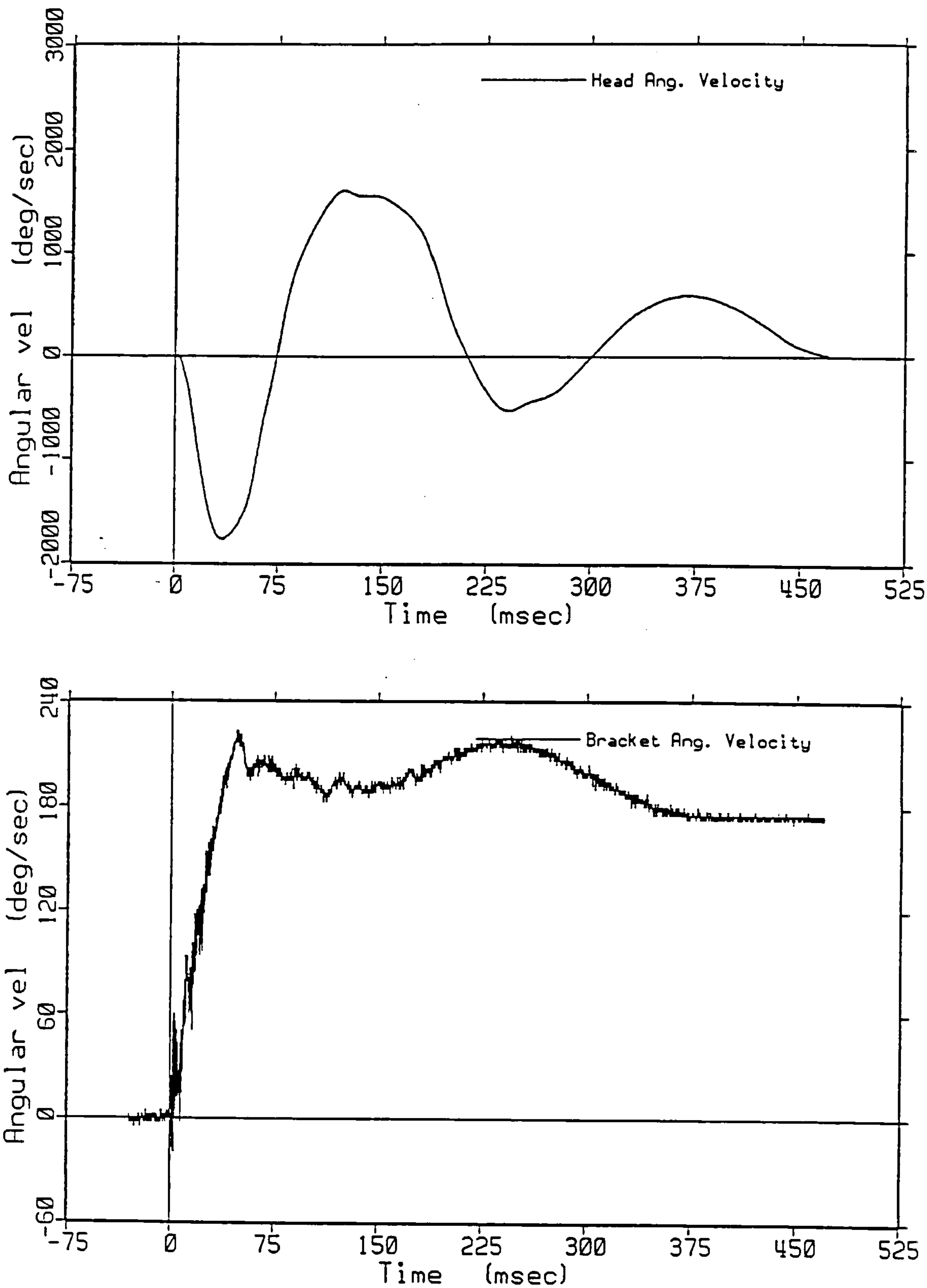


FIGURE 2 - Angular Velocity of Headform and Neck Bracket for Pendulum Extension Test #V34NE1

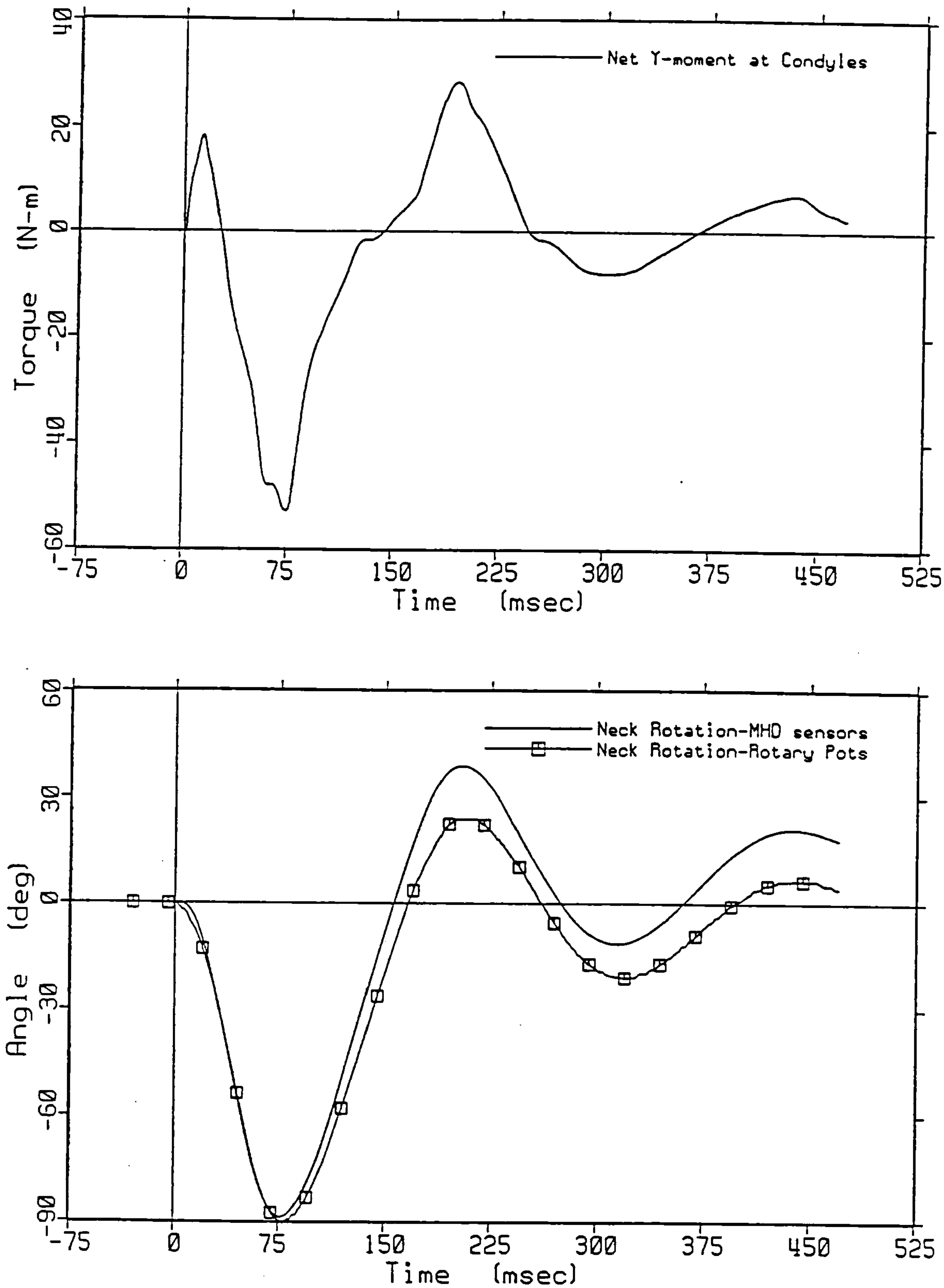


FIGURE 3 - Neck Y-Moment and Rotation for Pendulum Extension Test #V34NE1

TRC301 which involved a driver using a three point restraint system is examined first. The head and sled acceleration curves are given in figures C1 and C2 of appendix C. Of greater interest are figure 5, which shows the head and torso angular velocity, and figure 6, which shows the measured Y-moment about the occipital condyles and the total neck rotation. Figure 5 is presented to give an indication of the types of motion which the dummy is undergoing. What is really of interest, however, is the fact that, although the net moment exceeds the Mertz criteria of negative 57 N*m at about 80 milliseconds, the corresponding rotation is less than 20 degrees in extension. This loading was caused when the top of the head slid downward along the top edge of the steering wheel, causing a considerable shear force along the top of the head and moment in the neck. This is certainly not hyperextension and, for this reason, Mertz's criterion does not even apply in this case. In fact, there are many types of neck loading which occur in crash testing that can not be analyzed using the Mertz criterion. This point will be discussed in greater detail later in this paper.

Now, data from test TRC302 is considered. In this test, a driver was used with an airbag restraint system. Once again, head and sled accelerations are given in appendix C (figures C3-C4). Figure 7 shows the Y-moment about the occipital condyles and the total neck rotation as measured by both the angular velocity sensors and film analysis. The general shapes of each curve for neck rotation agree fairly well. It should be clear from examining the choppiness of the film data that there is very significant error present. This is due to poor targeting of the dummy torso, and the large number of frames in which target locations could not be clearly identified due to obstructions, etc.

The next test to consider, TRC303, involved an unrestrained driver. The sled acceleration pulse was basically identical to that used in the two previous tests. The Y-moment from this test is shown in figure 8 along with the measured neck rotation angle for both film and angular velocity sensor data. The noteworthy feature to this test is the fact that although the peak moment measured is well above the Mertz criterion for injury and neck extension results, hyperextension does not occur. This is due to the fact that the

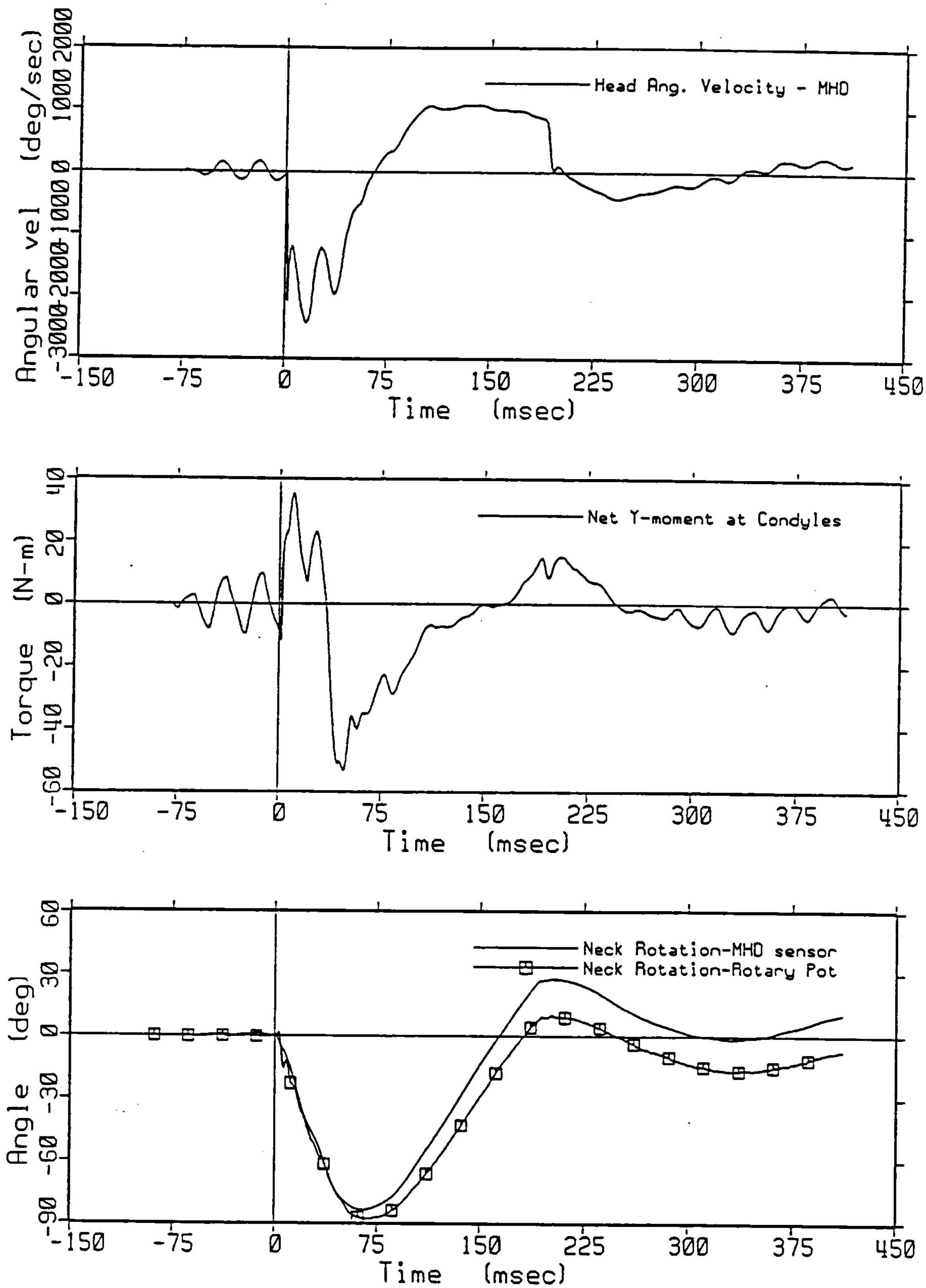


FIGURE 4 - Head Angular Velocity Total Neck Y-Moment and Total Neck Rotation for Impactor Extension Test #V34IE1

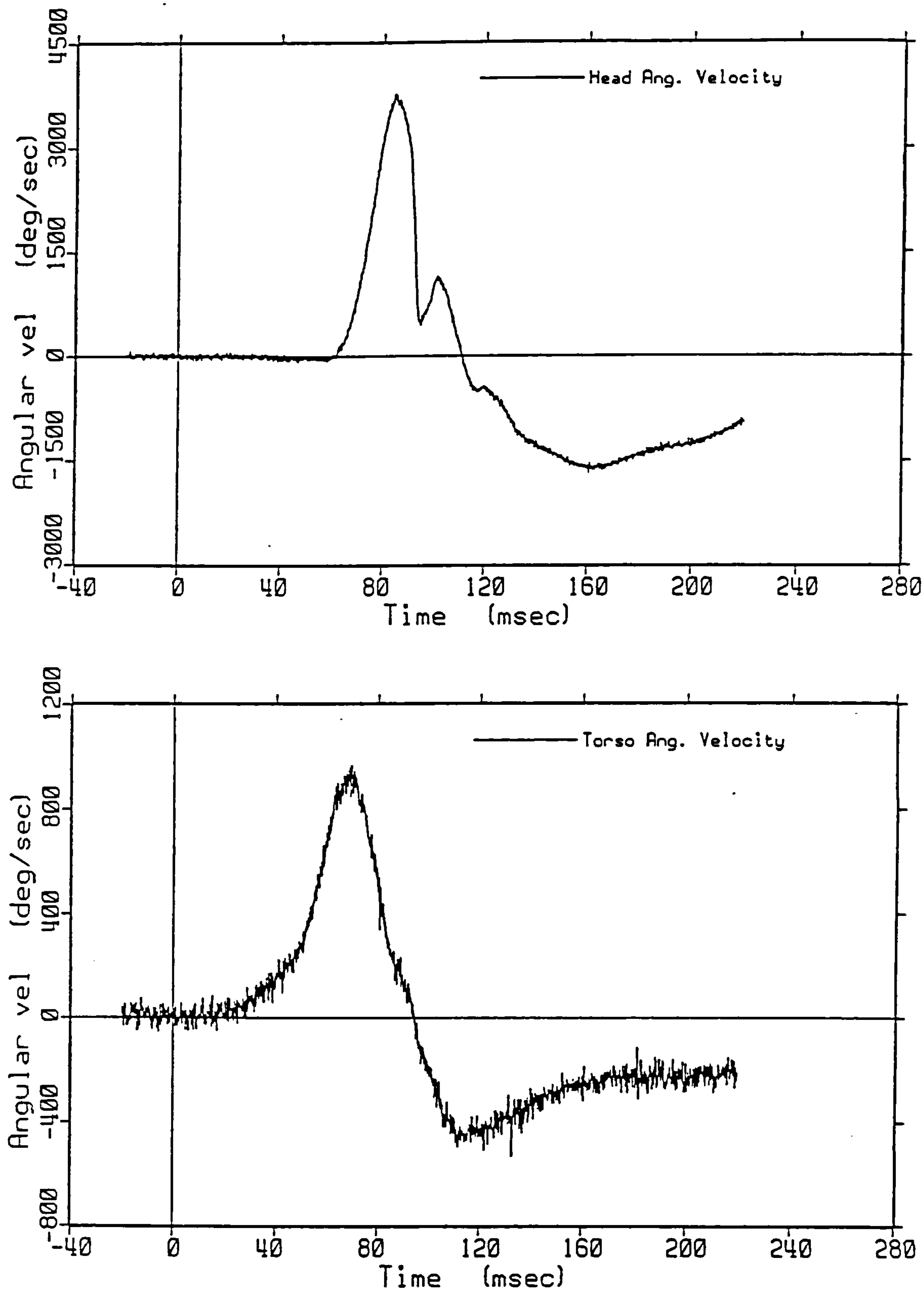


FIGURE 5 - Head and Torso Angular Velocities for 3-Point Belted Driver -- Sled Test TRC301

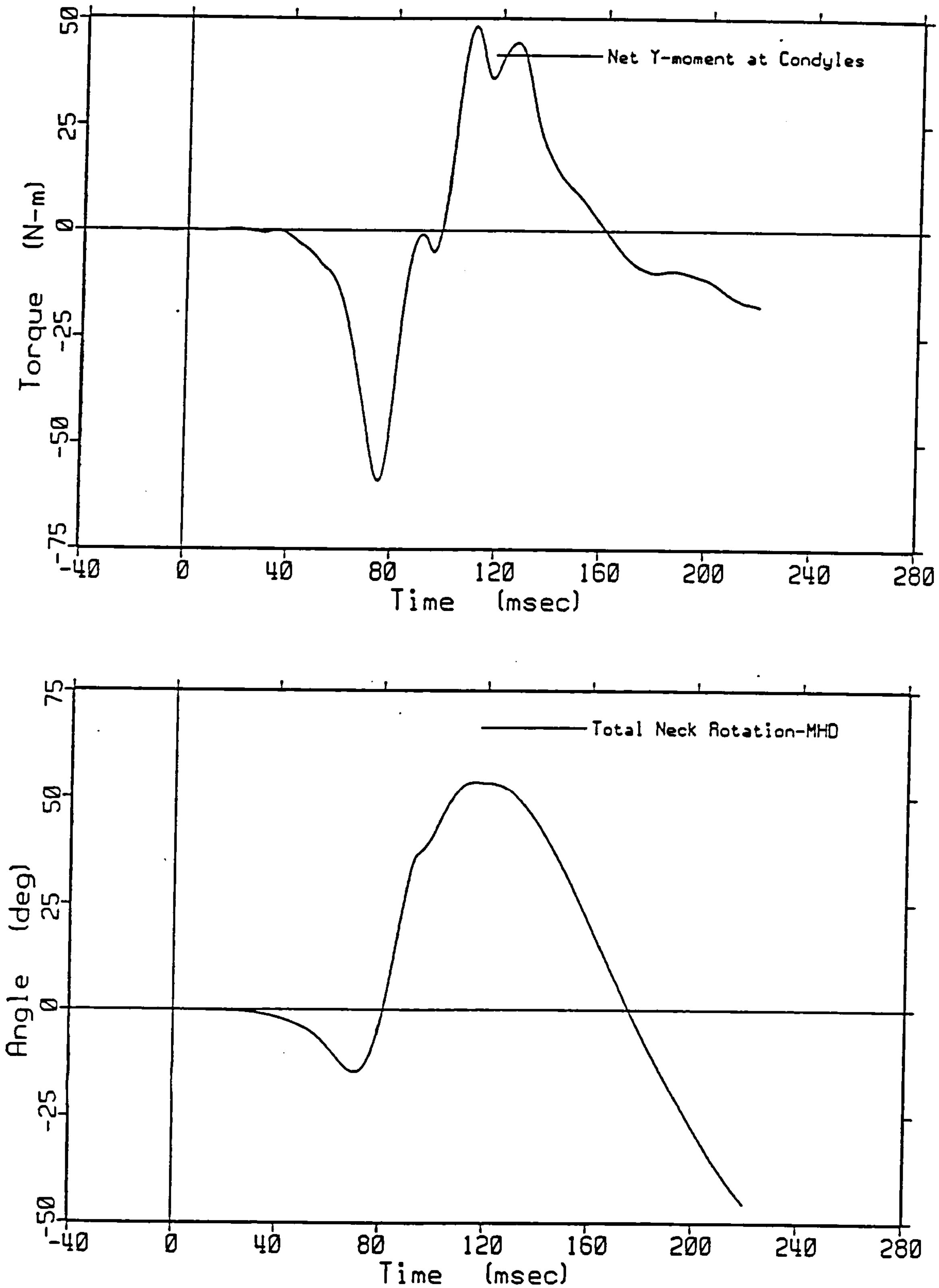


FIGURE 6 - Total Occipital Y-Moment and Neck Rotation for 3-Point Belted Driver - - Sled Test TRC301

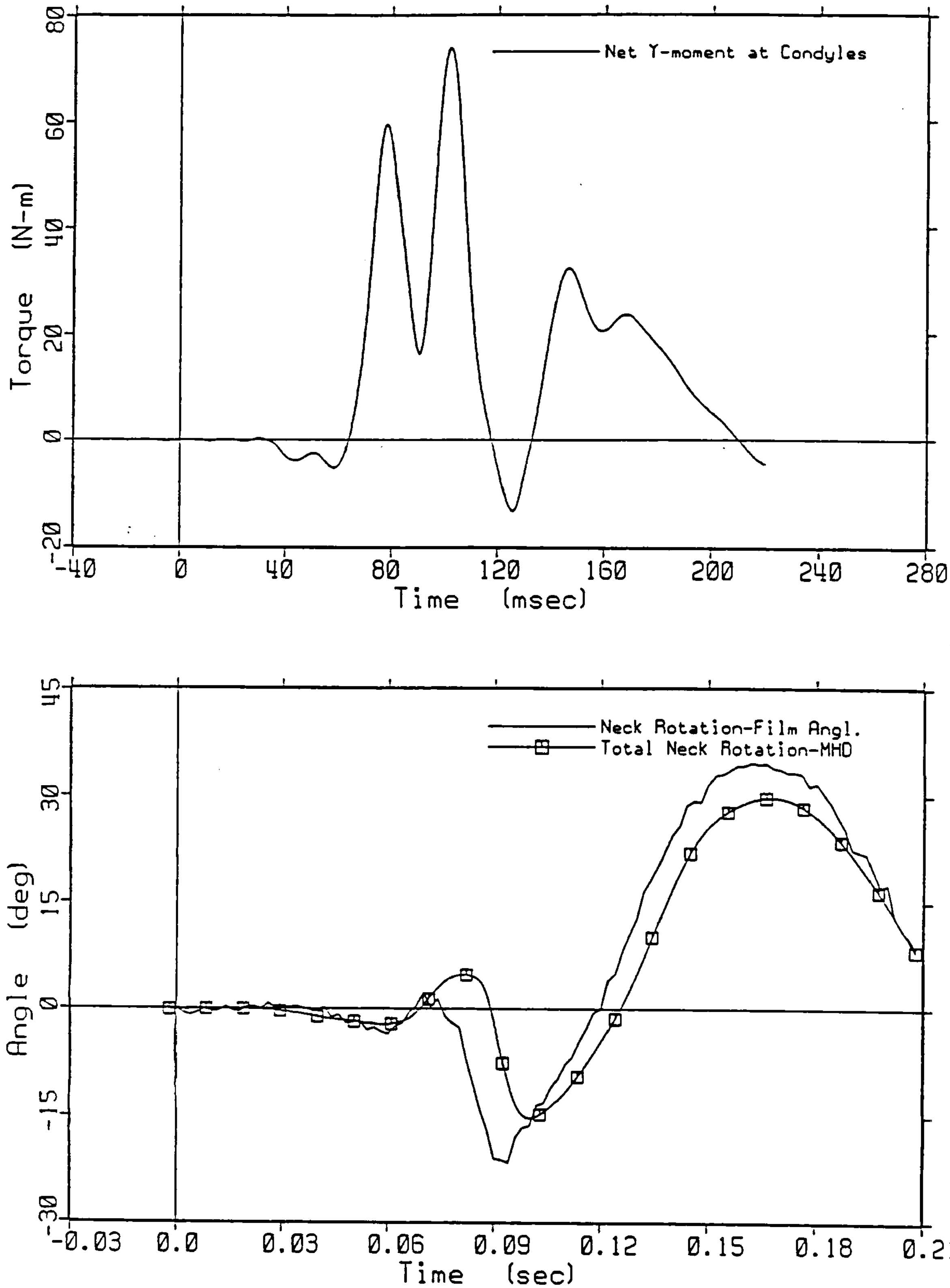


FIGURE 7 - Total Occipital Y-Moment and Neck Rotation for Unrestrained Driver With Airbag -- Sled Test TRC302

forward rotation of the torso is limited by the steering wheel while the rearward rotation of the head is dictated by the windshield. This represents a very different type of loading than that investigated by Mertz and thus the loading and response characteristics do not fall within the Mertz corridor. Examining figure 8, one again sees that the film and sensor data for the neck rotation agree fairly well considering the uncertainty inherent in the film analysis data.

The final test, TRC304, involved a unrestrained passenger. This test was actually identical to the previous test except there was no steering column. With this in mind, one would expect extreme results since the steering wheel/windshield geometry served to prevent excessive neck extension in the last test. Examining figure 9, which shows the net Y-moment and the total neck rotation, it is clear that significant injury would be a likely result.

4.0 DISCUSSION

Much effort has been expended since the development of the Hybrid III human surrogate test device in developing a procedure to determine the risk to the neck structure associated with car crashes. This work has primarily been based upon the establishment by Mertz and Patrick of a characteristic load/position envelope that defined the tolerance level of the neck. This work was limited to inertial "whiplash" type loads. The findings of Mertz and Patrick have been relied on because they provided a primarily load based injury criterion. The hyperextension requirement remained with this criterion, however, and much of the research that has been done has concentrated on discovering a way to objectively and practically measure the neck rotation concurrent with crash environments. A large part of the development has centered on new load measuring devices, such as the lower neck load cell, which it was hoped could be used to correlate against neck rotation. However, no consistently applicable rules were discovered which could be applied for this purpose.

Finally, a truly promising device has been developed which has the ability to give reliable neck rotation measurements during extreme dynamic loading

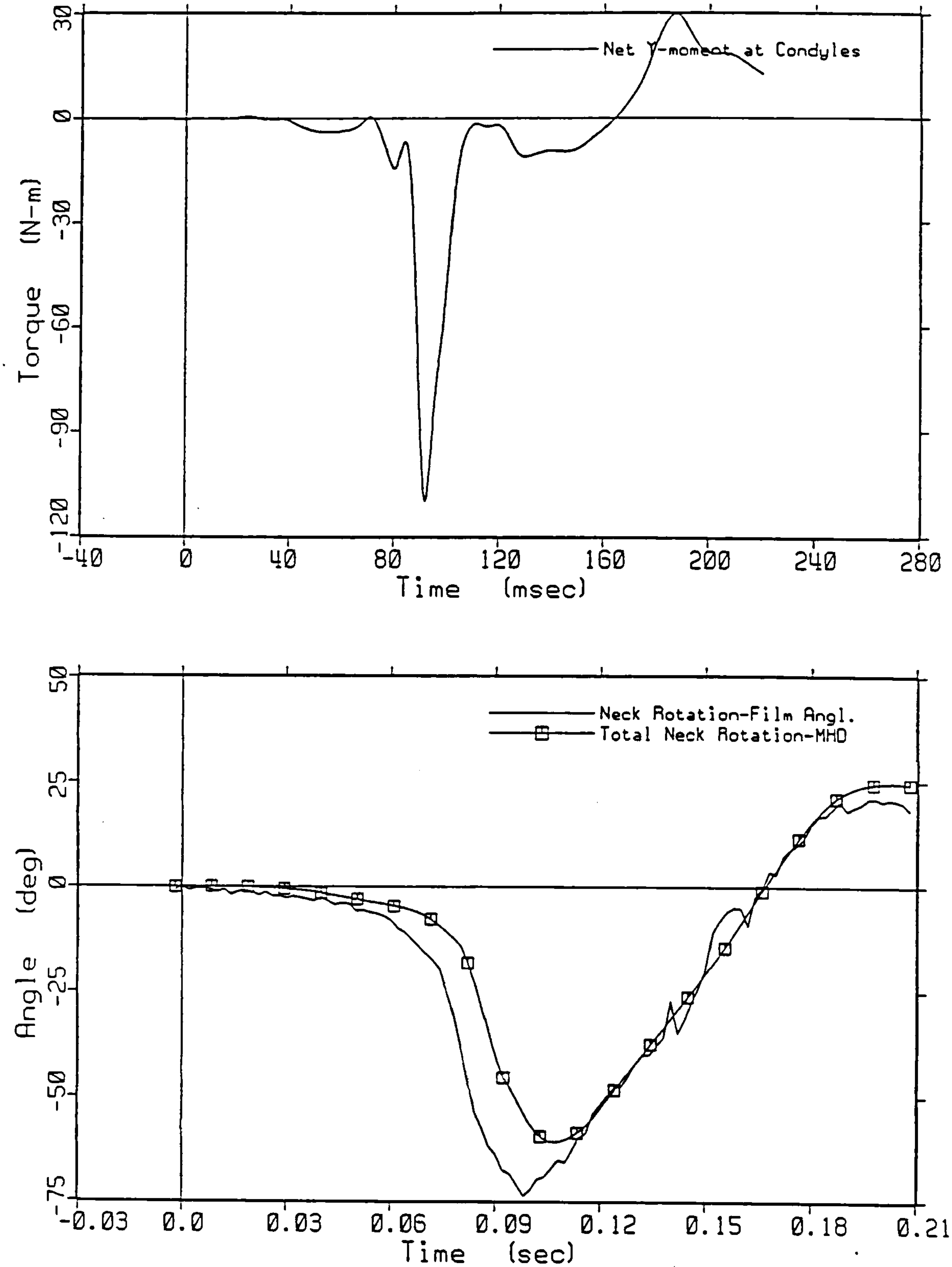
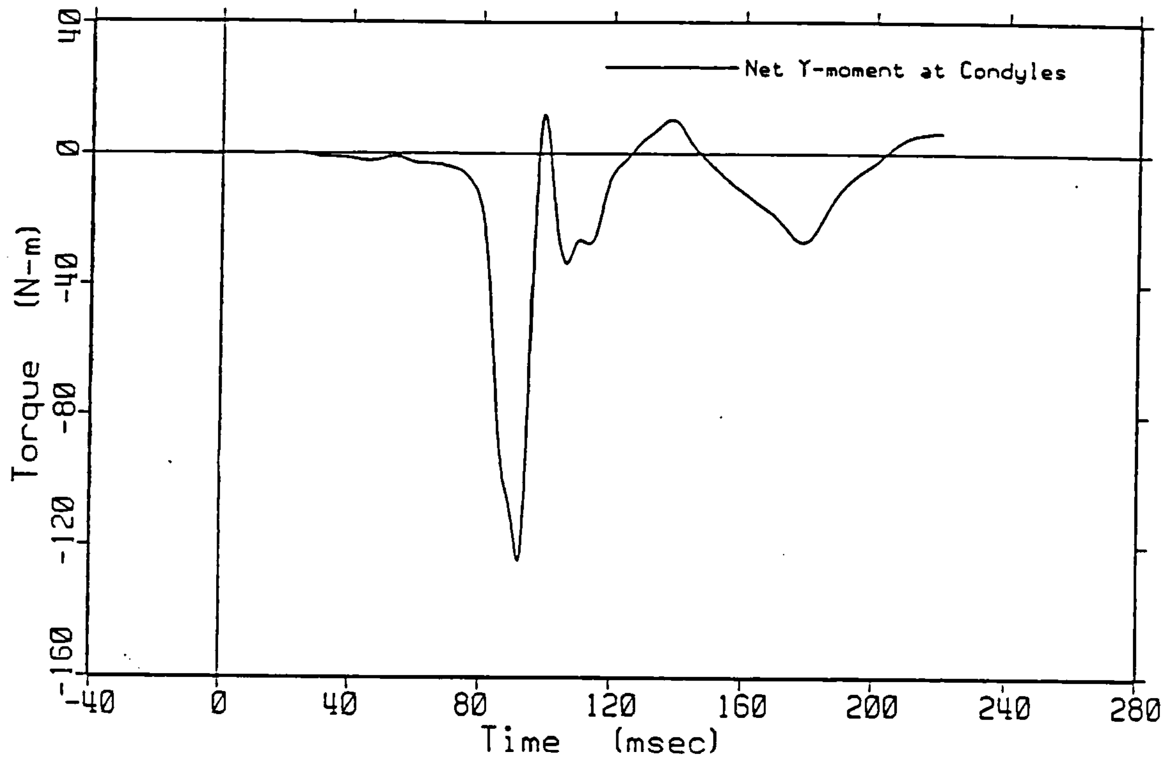


FIGURE 8 - Total Occipital Y-Moment and Neck Rotation for Unrestrained Driver -- Sled Test TRC303



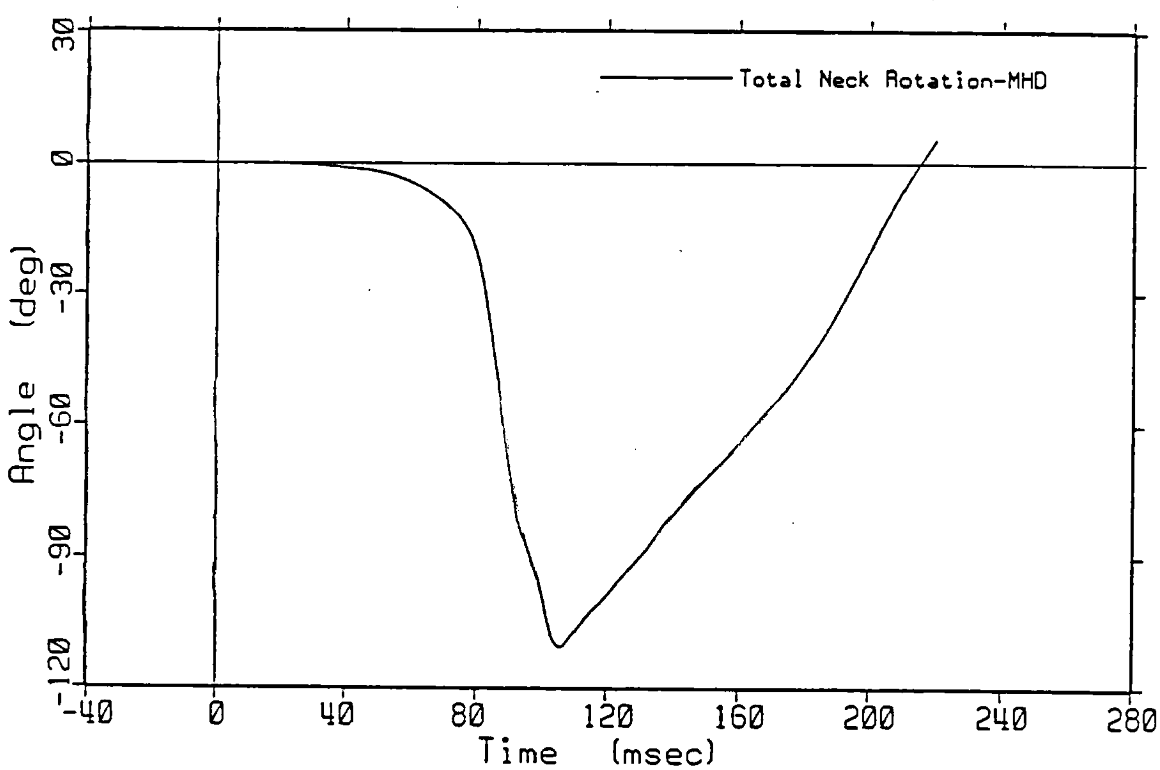


FIGURE 9 - Total Occipital Y-Moment and Neck Rotation for Unrestrained Passenger -- Sled Test TRC 304

situations. With this new magnetohydrodynamic sensor, the Mertz criterion can be accurately and faithfully applied to predict neck trauma in crash simulations. However, what can be done about cases in which the loading/response patterns observed in crash tests do not fall into the Mertz corridor?

An alternative injury criteria has been proposed by Gadd, et. al. (8). His work involved bending until failure a section of the cervical spine from cadavers which included two veterbral interfaces. He then recorded the total rotation measured and multiplied that number by four (to account for the eight vertebrae of the neck) thus determining the total amount of extension required to produce neck injury. He found that minor damage occurred with a total neck rotation of approximately 80 degrees. This number seems reasonable when one realizes that the Mertz corridor predicts significant neck injury for any rotation of more than about 90 degrees (1). The following table gives a comparison of the injury predicted by each criteria discussed for the sled and qualification tests analyzed. We will take 85 degrees to indicate significant injury for the Gadd criterion.

5.0 CONCLUSIONS

In considering the usefulness of the lower neck load transducer for determining the neck rotation angle, several tests were examined. The objective was to find some correlation between the angular position of the head with respect to the torso and measurements taken with the transducer. However, several attempts produced no such correlation. As hyperextension injuries were of primary concern, those tests involving flexion were not examined closely. Torque and shear measured at the lower neck position were both considered, but neither displayed a correlation with neck position that was common for the variety of loading conditions examined here. The angular impulse displayed a nearly linear relationship with the neck position for the inertial loading condition of the head/neck pendulum tests and simple forehead impact tests, but the results from the airbag and upper interior impact tests were not consistent. This examination has shown that the extended position of the neck is not easily determined from measurable forces and/or torques, especially when loading patterns are variable.

TABLE 4

TEST #	DESCRIPTION	LOAD TYPE	MERTZ PASSED	GADD PASSED
V34NE1	PENDULUM EXT.	INERTIAL	YES*	NO
V34NE2	PENDULUM EXT.	INERTIAL	NO	NO
V34NE3	PENDULUM EXT.	INERTIAL	NO	NO
V34IE1	IMPACTOR EXT.	IMPACT	YES	YES
V34IE2	IMPACTOR EXT.	IMPACT	YES*	NO
V34IE3	IMPACTOR EXT.	IMPACT	YES*	NO
TRC301	SLED TEST W/ BELTED DRIVER	COMBINED	YES	YES
TRC302	SLED TEST W/ AIRBAG	INERTIAL	YES	YES
TRC303	SLED TEST W/ UNRESTRAINED DR.	IMPACT	YES	YES
TRC304	SLED TEST W/ UNRESTRAINED PASS.	IMPACT	NO	NO

*Although each of these passed the Mertz criterion, the margin was very small

Since no success was found using the lower neck load transducer to measure neck rotation in various loading conditions, efforts turned to newly developed angular velocimeters. These new devices, which can withstand hostile impact environments, give direct measurement of their angular velocity. This output can then be integrated to determine the angle through which the sensor, and thus any rigid body to which the sensor is attached, has rotated. The accuracy and reliability of the sensors was tested through several head/neck calibration tests and crash simulations. Comparisons were made between results from sensor data and more orthodox methods of angle measurement such as the linked potentiometer system and high-speed film analysis. Although some differences existed, the results were in very good agreement during the high impact/response periods of the first 150-200 milliseconds.

With these findings, it seems that these sensors finally offer a reliable means to determine the likelihood of neck injury in accident simulations. Utilization of these sensors allows the application of either one of the following two possible neck extension injury criteria in the Hybrid III dummy:

1. Gadd's research indicated that minor injury of the neck would result when extension of the neck exceeded 80 degrees rotation. This criterion could be determined directly using the MHD sensors as described in this report.

2. The Mertz neck extension injury criterion states that the moment about the occipital condyle may not fall below minus 57 N*m under hyperextension conditions. This criterion could be applied by using the MHD sensors to determine hyperextension (80-90 degrees rotation), and the upper neck load cell to measure the moment about the occipital condyles.

Finally, while the new sensor data agrees well with established measurements, agreement is not exact. However, these new devices provide the only reliable, objective means available to measure the rotation of the neck in crash environments. Another method exists which requires an array of nine accelerometers, but because of the large amount of processing required and the need to have precisely controlled initial conditions, large errors are produced when attempting to determine position. Further testing of the new sensors which utilize a controlled input should be carried out to determine the sources of the difference, but it seems the angular velocimeters sufficiently measure rotation angle for the purposes considered here.

6.0 REFERENCES

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APPENDIX A

Description of Test Procedures

Head / Neck Pendulum Calibration Tests

The head/neck pendulum tests were designed to provide an inertial loading of the neck structure. The head/neck assembly was secured to the end of a rigid pendulum as shown in Figure A-1. The inertia of the head provides a bending load at the end of the neck when the pendulum's motion is arrested at the end of its stroke. The neck extension and/or flexion angles were measured with the 2 rotary potentiometer linkage system illustrated in Figure 1 in the main body of this report. Both the flexion and extension tests, used for the analysis in this report, were conducted according to the standard Hybrid III neck calibration procedure. This procedure is described in the Hybrid III User's Manual, which is available from the Society of Automotive Engineers, Inc. in Warrendale, PA.

Linear Pendulum Forehead Impact Tests

These tests were conducted as an earlier part of this Rulemaking Support project (3). A linearly guided, free motion pendulum was used to strike the forehead of the Hybrid III head form (Figure A-2). The Hybrid III head/neck assembly was secured to the test fixture base through the six-axis, lower neck transducer. Neck extension was measured with the 2 rotary potentiometer linkage shown in Figure A-1 in the main body of this report.

HYGE Sled: 2-Point Belt Crash Simulation

These tests were conducted as part of an investigation of 2-point belt restraint system parameters' effect on the response of Hybrid III (5). A sled buck was built using interior components from a Volkswagen Golf. The relationships between components were adjustable so that the system's parameters could be varied. The tests used in this analysis did not have the standard knee bolster, used a stiffer than standard dash, and had the belt retractor moved forward of the standard position. The sled's V was approximately 57 km/h in these tests. The dummy's neck response was recorded by high-speed movie film. Since the Hybrid III's neck response was primarily flexion, this test was not examined closely but was included as a secondary check of relationships that might have been observed for the extension tests.

HYGE Sled: Airbag Restraint

This test was included in a study of seat belt/airbag phasing (6). A Hybrid III was used as a driver surrogate in a test of only the airbag restraint in the Ford Tempo. The sled buck was built from the passenger compartment of a Ford Tempo. The test's V was approximately 57 km/h and the Hybrid III's neck response was recorded by high-speed movie film.

HYGE Sled: Front Header Impact

This test was included in an investigation of upper interior head protection (7). The sled buck was constructed from the passenger compartment of a Ford Tempo. An unrestrained Hybrid III was seated in the passenger side in such a way that the dummy's head would strike the front header of the Tempo's windshield. The ΔV of the sled in these tests was approximately 32 km/h. Again, the dummy's neck response was recorded by high-speed movie film.

HYGE Sled: 3-Point Belt Crash Simulation-TRC301

This test was similar to the 2-point belt test discussed earlier in all respects except a Ford Tempo sled buck with a three point belt was used instead of the Volkswagen Golf.

HYGE Sled: Airbag Restraint-TRC302

This test was identical to the airbag sled test described earlier.

HYGE Sled: Unrestrained Driver-TRC303

This test utilized the same Ford Tempo sled buck as the previous two. An unrestrained Hybrid III was seated in the driver's seat, and the sled's V was once again approximately 57 km/h.

HYGE Sled: Unrestrained Passenger-TRC304

Once again, the Ford Tempo sled buck was used after necessary repairs were made. Because no passenger seat was available, a Hybrid III was placed in the driver side of the sled buck with the steering column assembly removed. The V of the test was approximately 57 km/h.

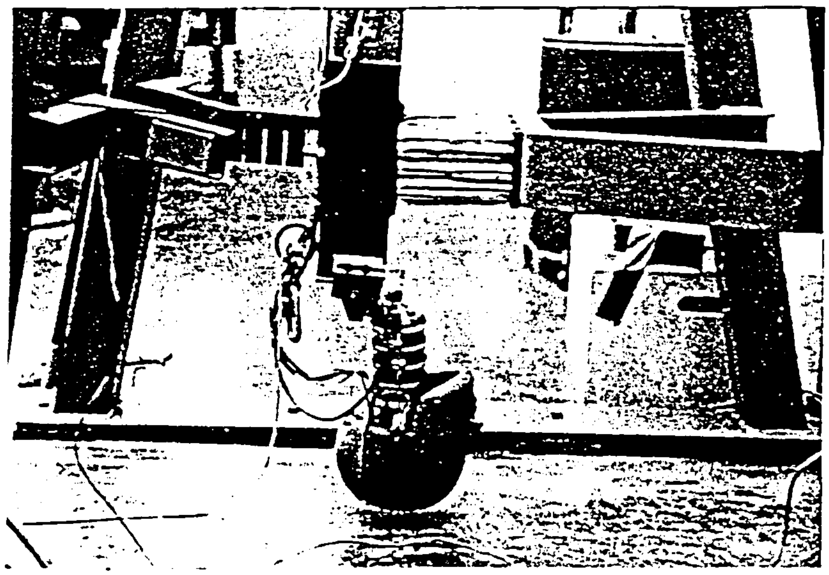


FIGURE A-1 - Pendulum Flexion Test Setup

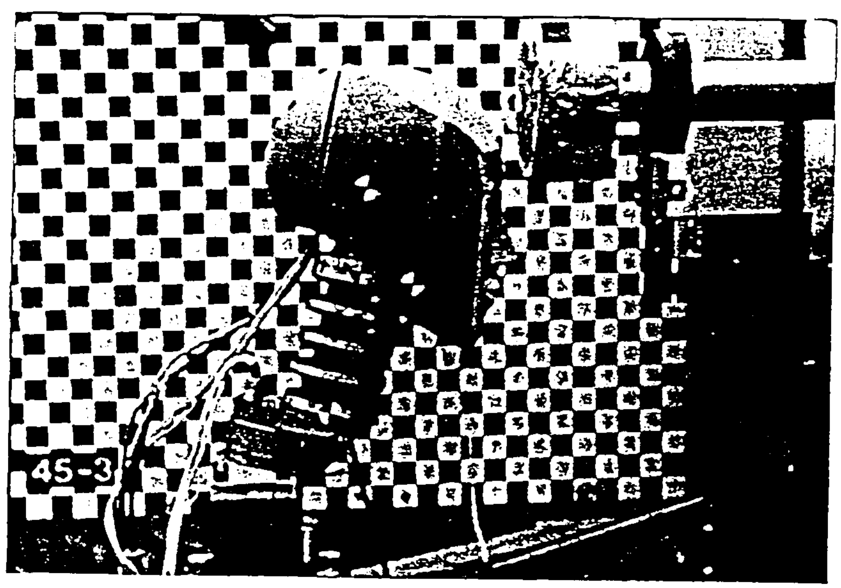
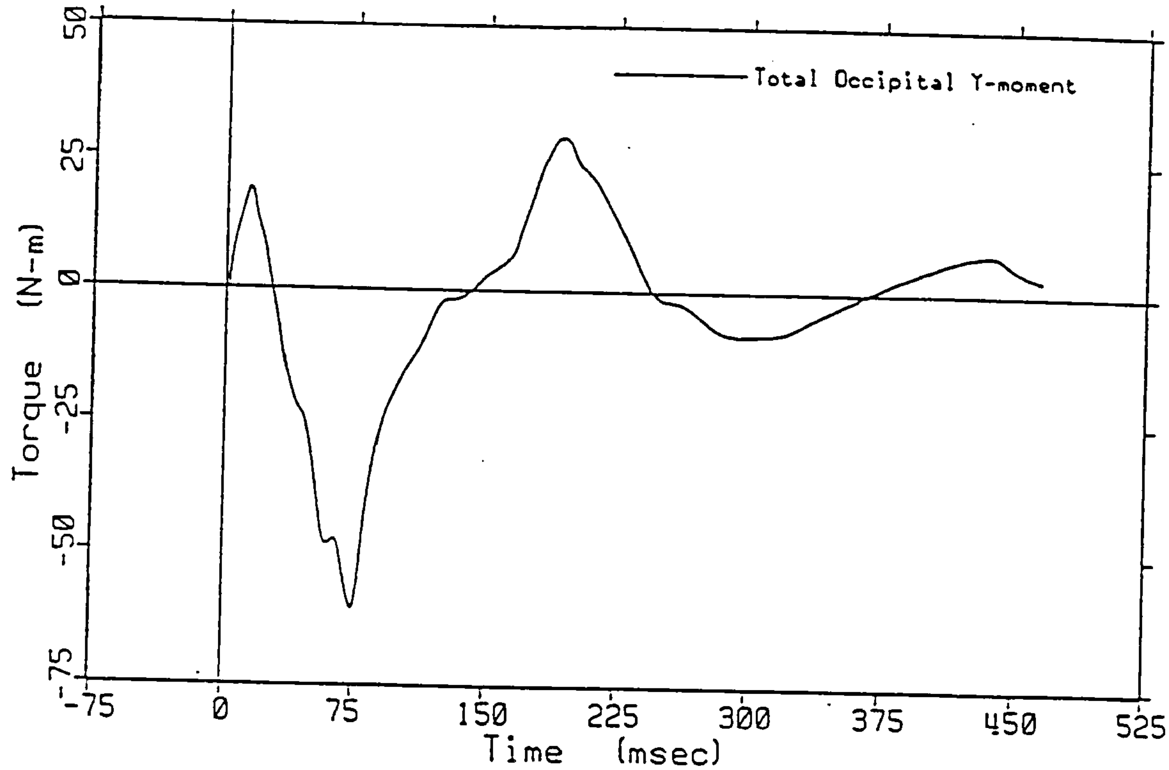


FIGURE A-2 - Linear Impactor Extension Test Setup

APPENDIX B

Angular Velocity Sensor Qualification Test Data



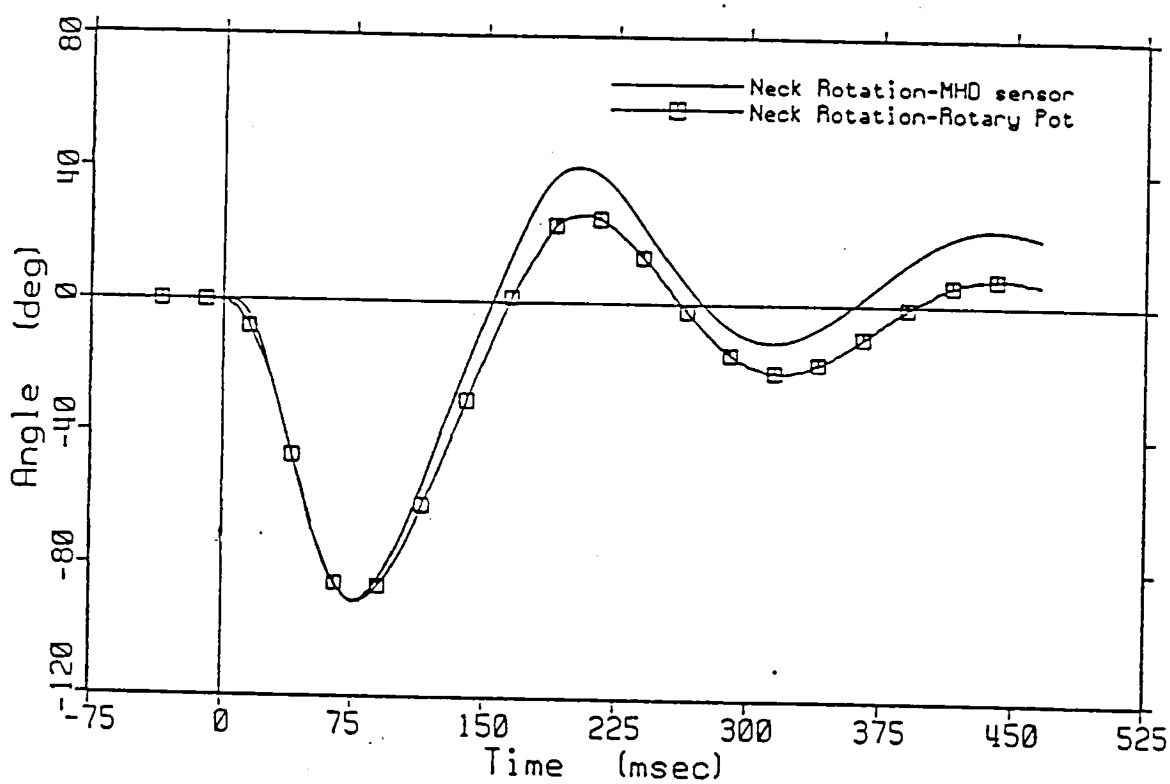


FIGURE B-1 - Total Occipital Moment and Neck Rotation for Pendulum Extension Test #V34NE2

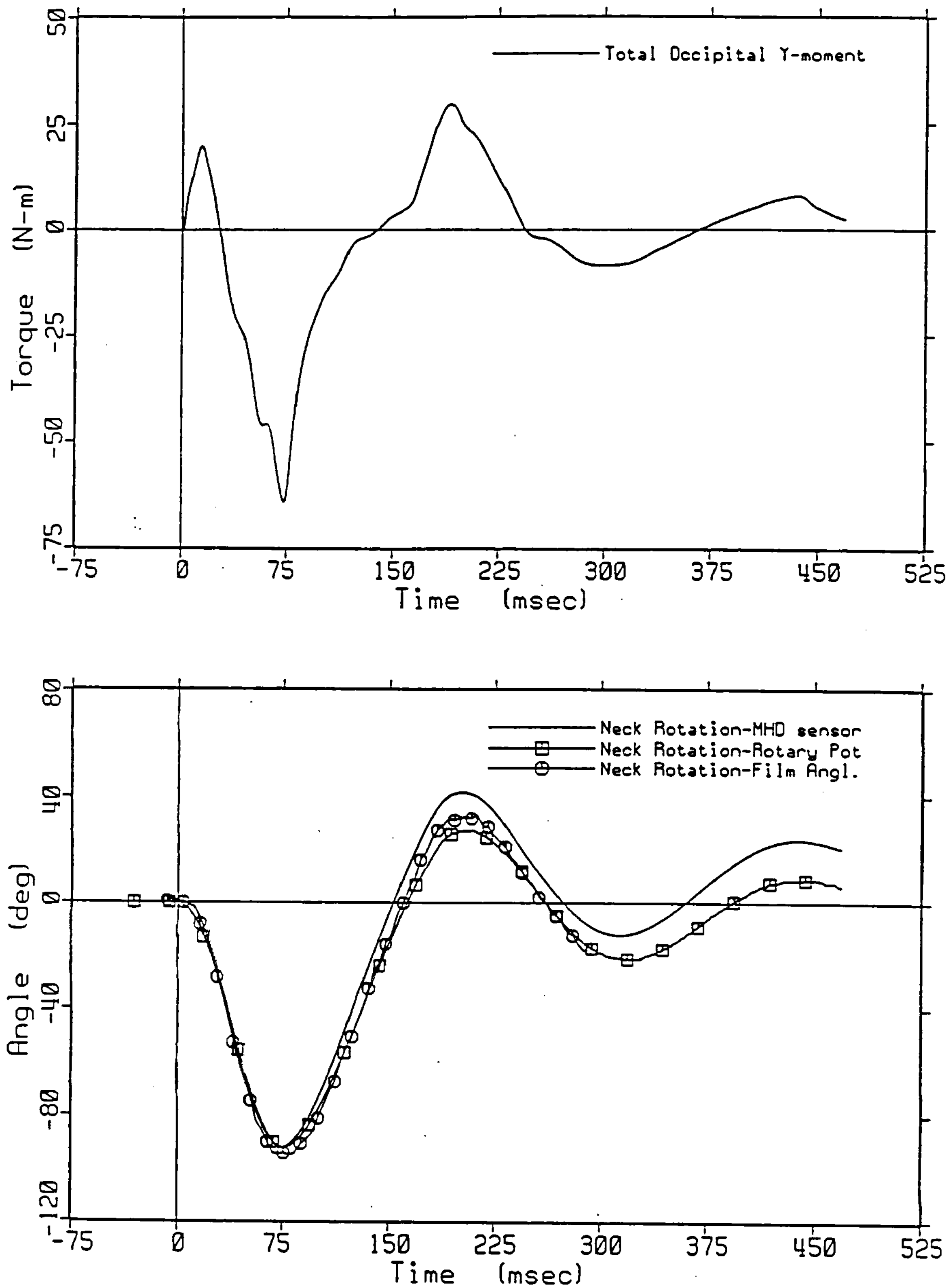
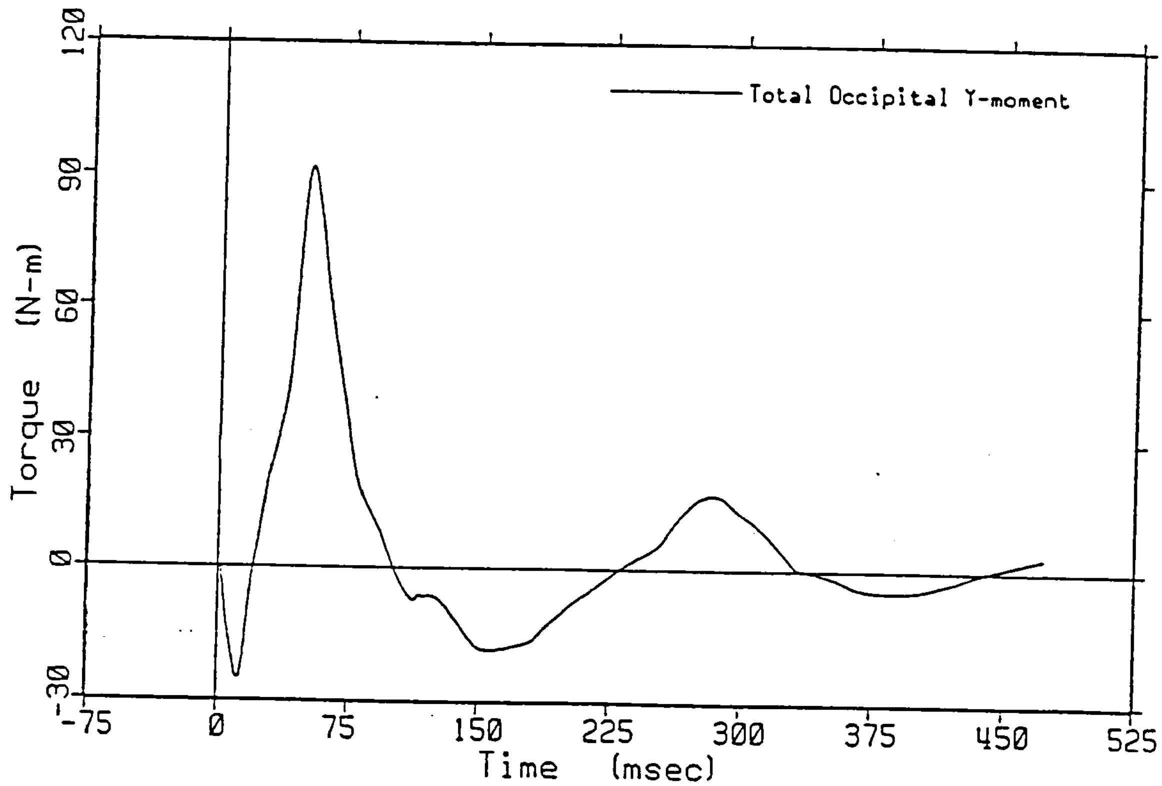


FIGURE B-2 - Total Occipital Moment and Neck Rotation for Pendulum Extension Test Number V34NE3



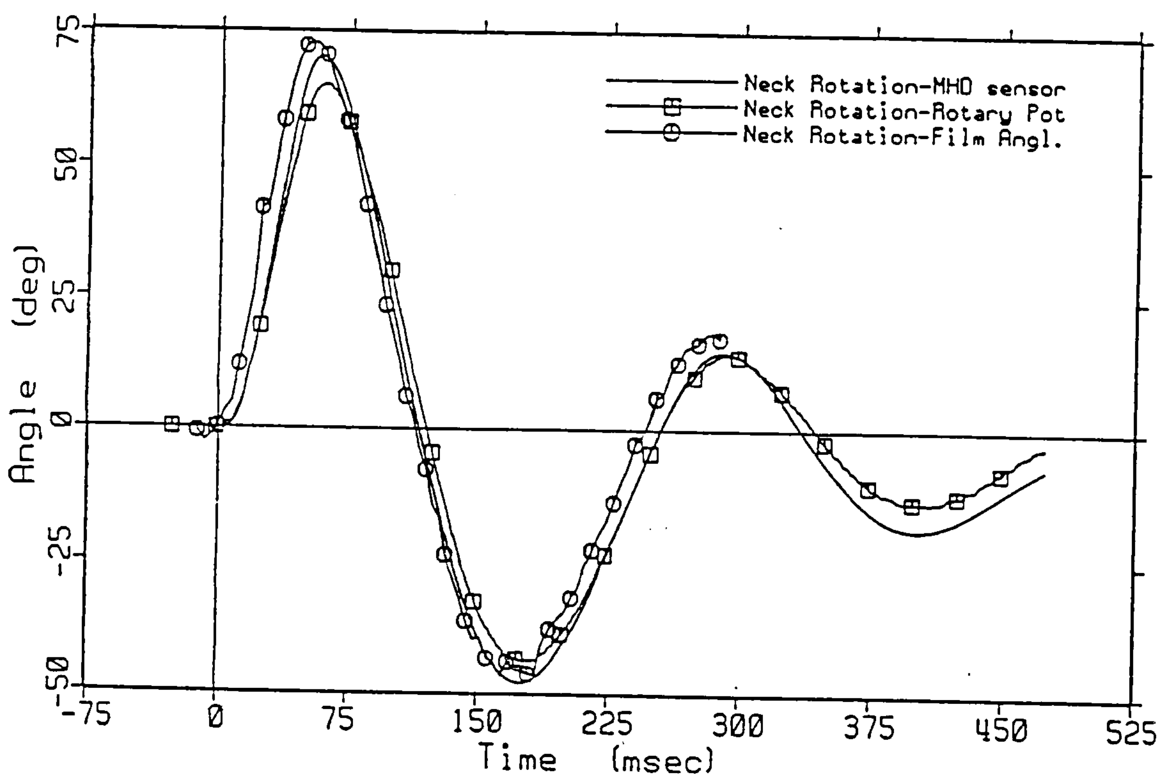


FIGURE B-3 - Total Occipital Moment and Neck Rotation for Pendulum Flexion Test #V34NF1

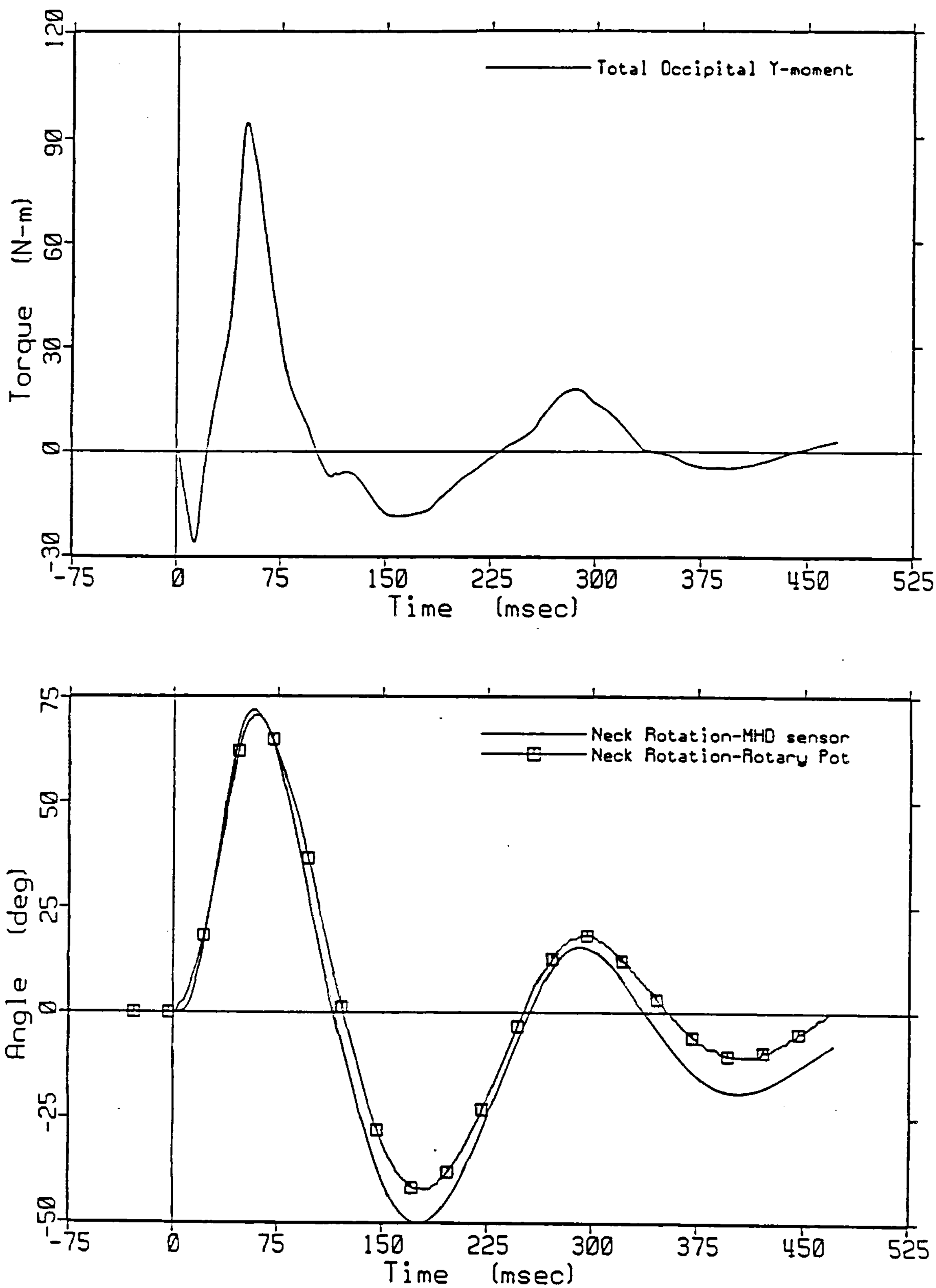
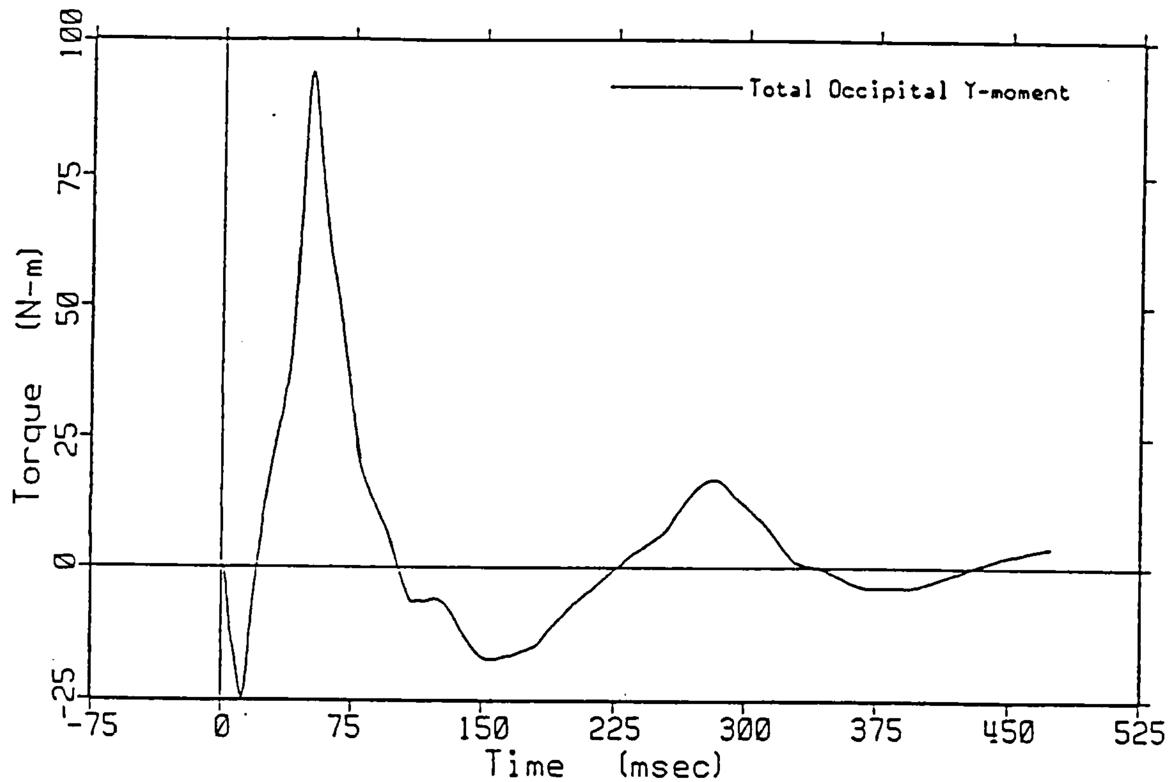


FIGURE B-4 - Total Occipital Moment and Neck Rotation for Pendulum Flexion Test #V34NF2



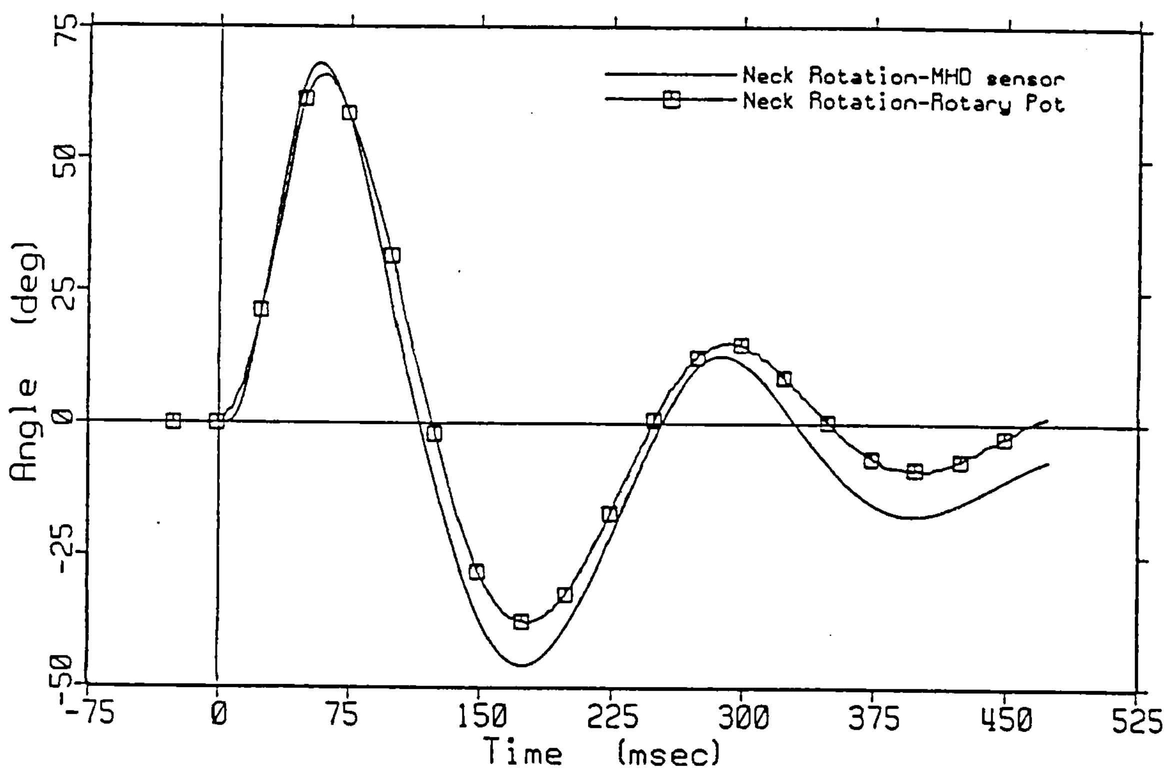
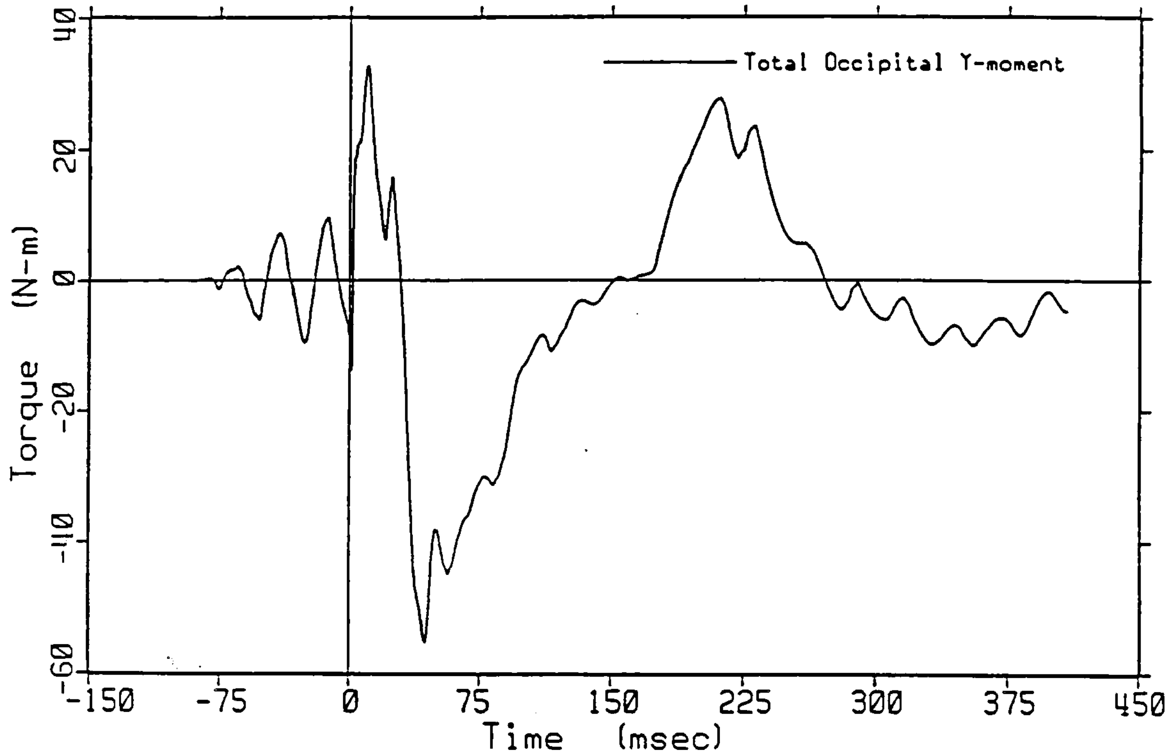


FIGURE B-5 - Total Occipital Moment and Neck Rotation for Pendulum Extension Test #V34NF3



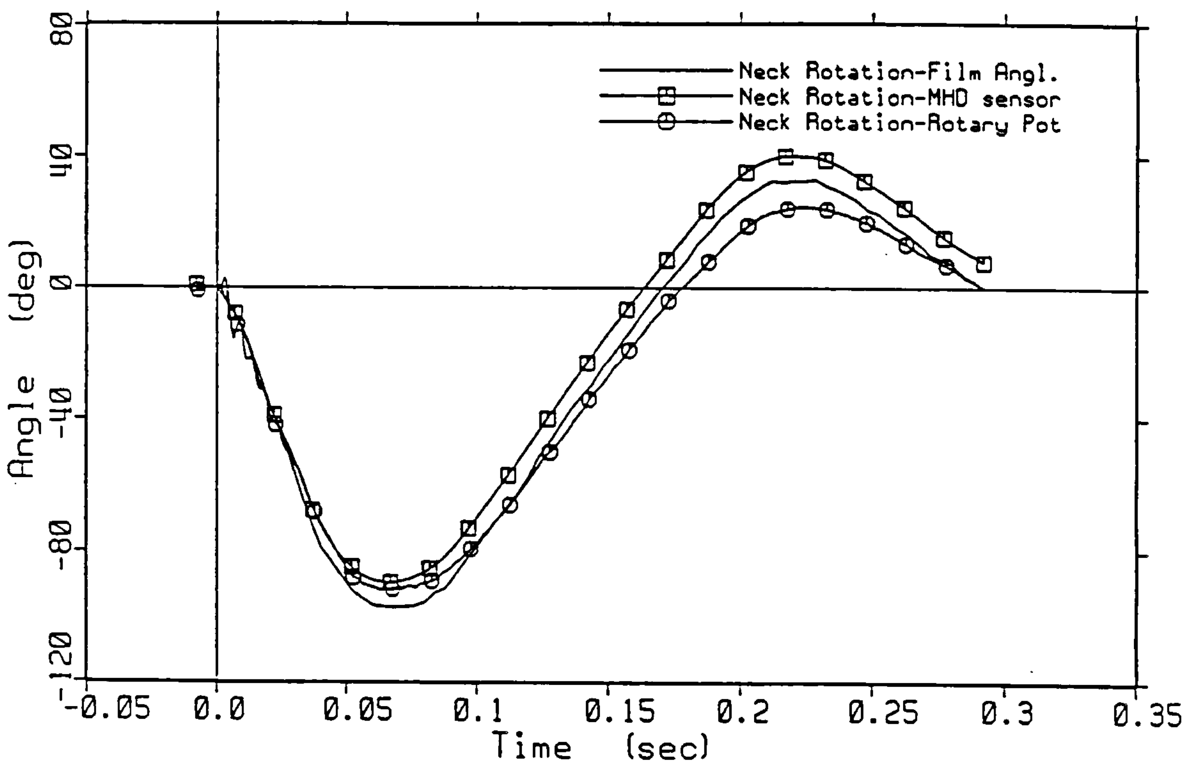
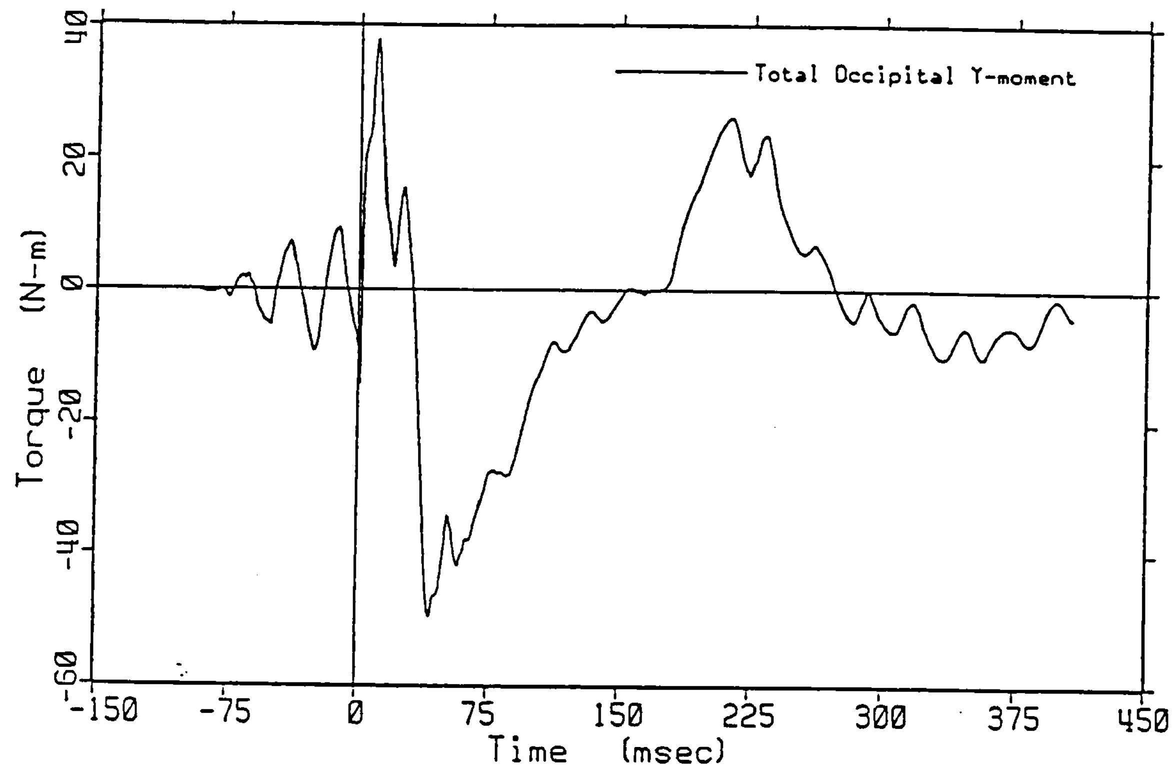


FIGURE B-6 - Total Occipital Moment and Neck Extension for Linear Impactor Test #V34IE2



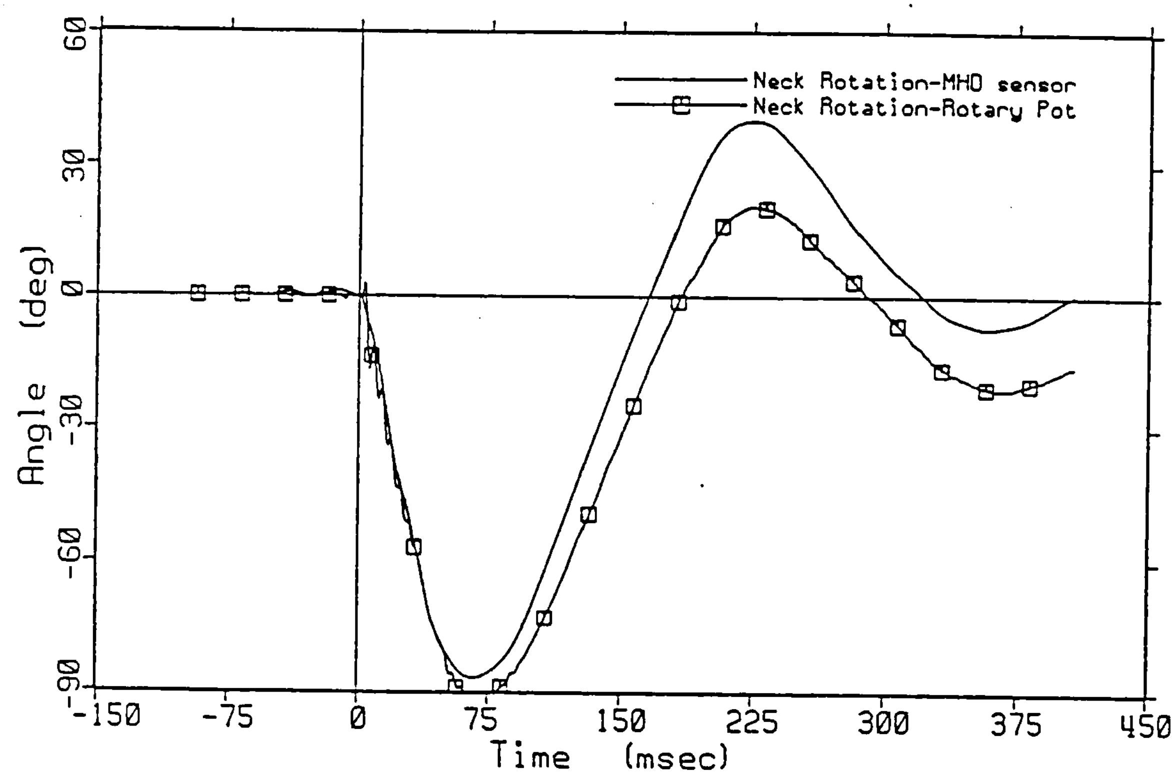


FIGURE B-7 - Total Occipital Moment and Neck Rotation for Linear Impactor Test #V34IE3

APPENDIX C

Angular Velocity Sensor HYGE Sled Test Data

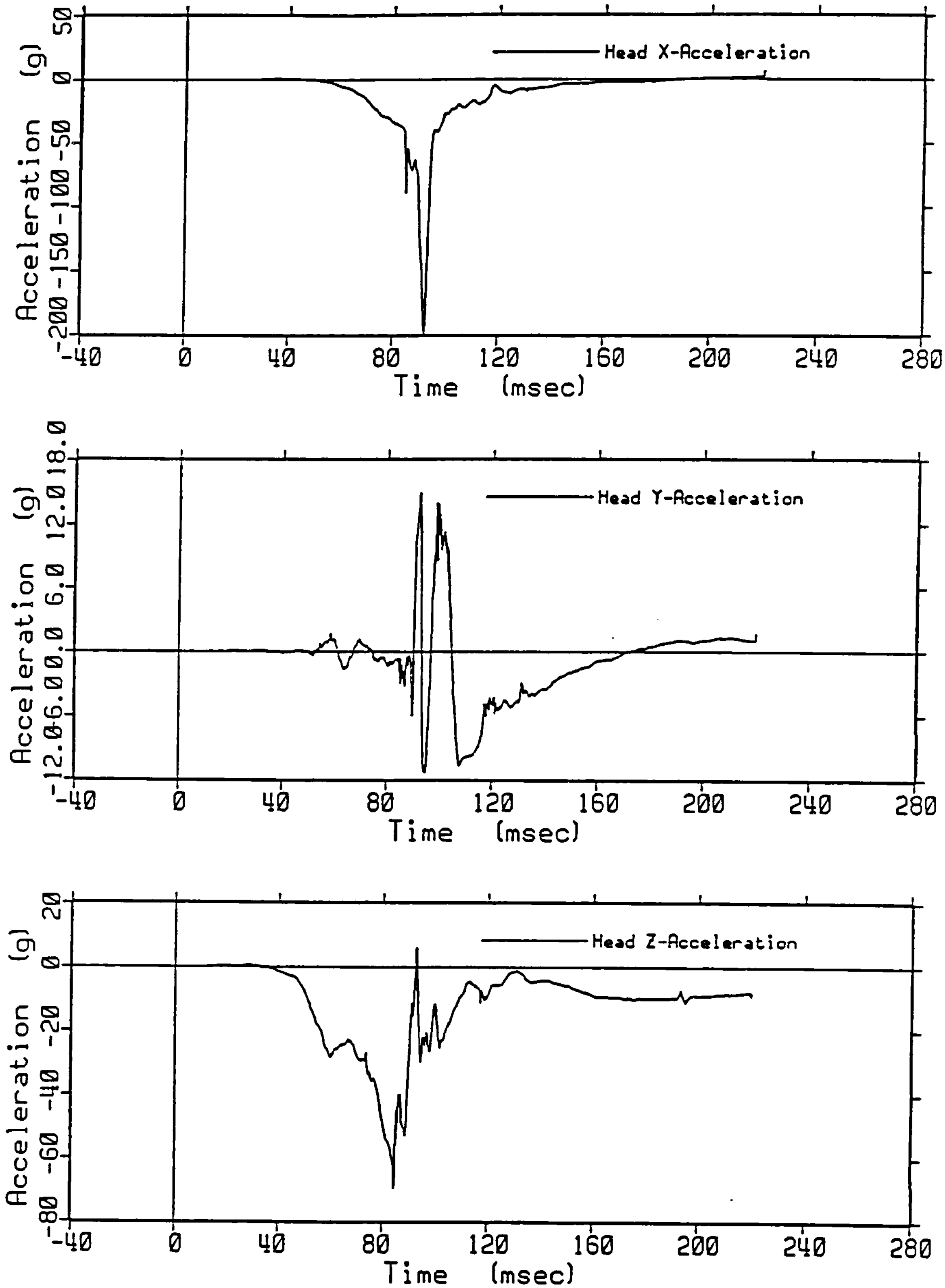


FIGURE C-1 - Triaxial Head Acceleration for Sled Test with 3-Point Belted Driver -- Sled Test TRC301

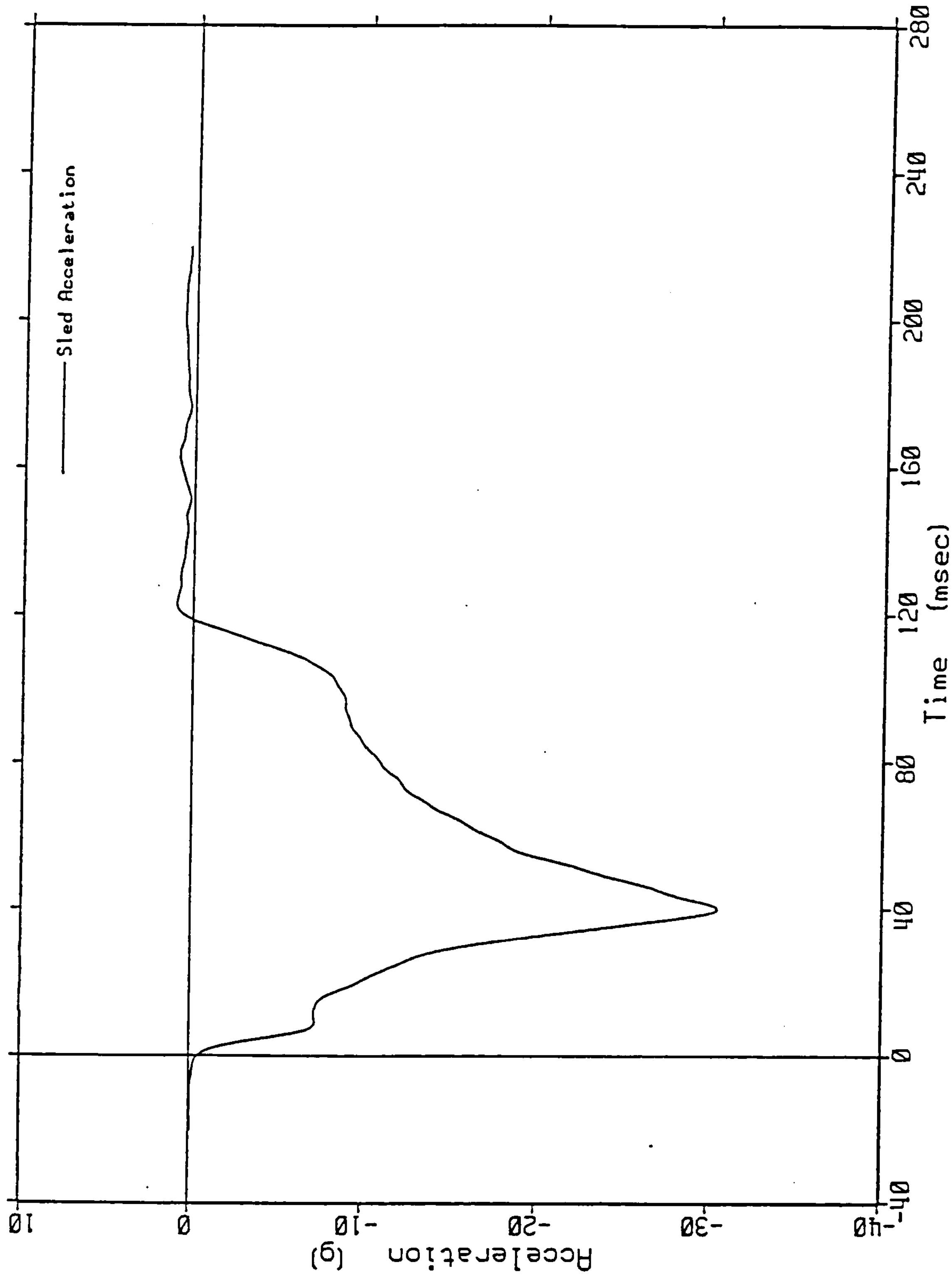


FIGURE C-2 - Sled Acceleration for Sled Test with 3-Point Belted Driver -- Sled Test TRC301

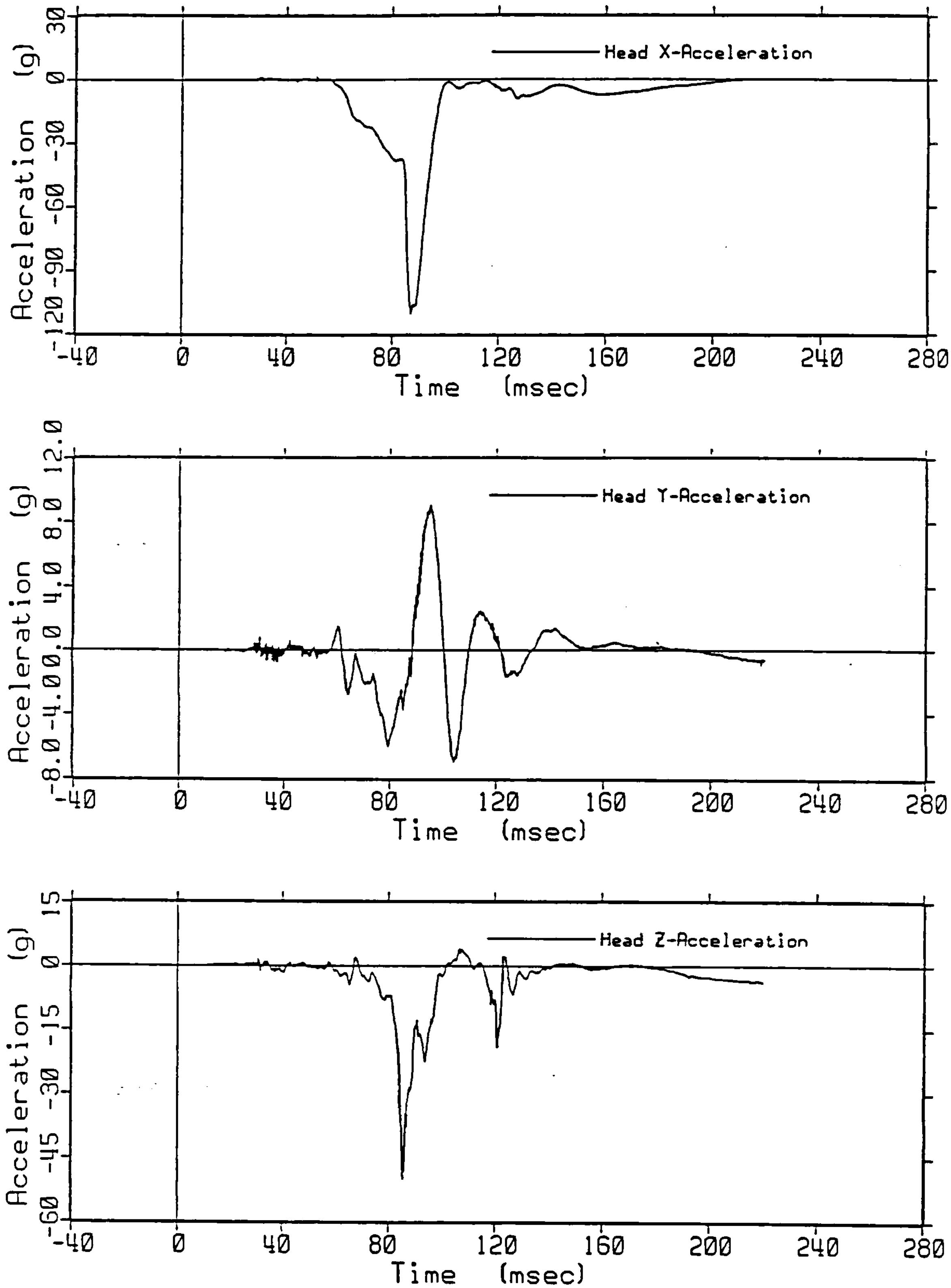


FIGURE C-3 - Triaxial Head Acceleration for Sled Test Involving Unrestrained Driver with Airbag -- Sled Test TRC302

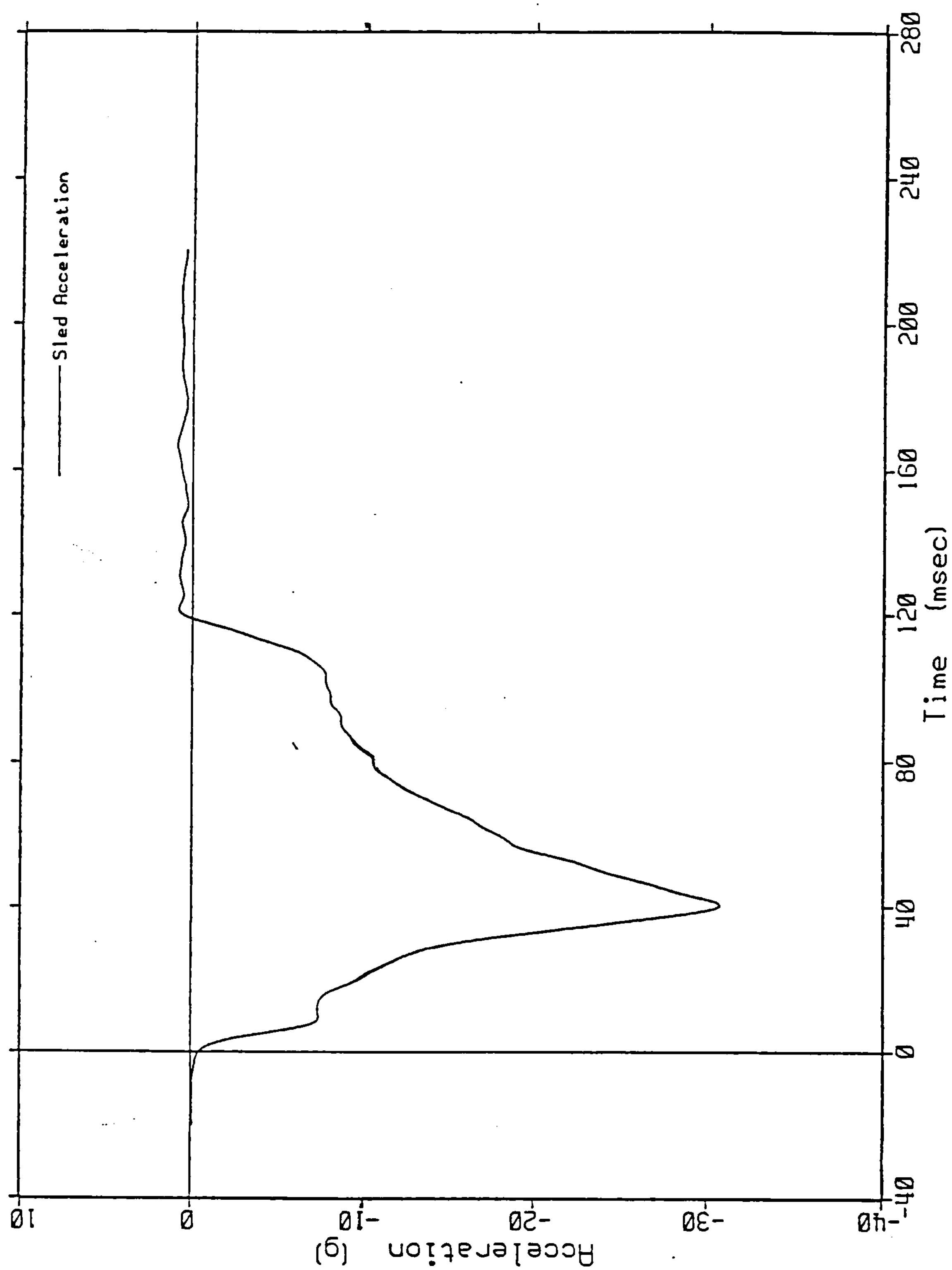


FIGURE C-4 - Sled Acceleration for Sled Test Involving Unrestrained Driver with Airbag Sled Test TRC302

PAPER: MEASUREMENT OF NECK HYPEREXTENSION IN A CRASH ENVIRONMENT

SPEAKER: Brian Tanner, Transportation Research Center of Ohio

Question: Neil Watson Triangle Research and Development Corp.

A couple of comments. Firstly, nomenclature and communication: although rotation may be correct from an engineering point of view, it's really confusing from a clinical point of view because flexion and extension have no rotatory connotations in clinical nomenclature. In other words, turning your neck to the right is rotating, turning to the left is rotating but moving forward and backward, flexing and extending are flexing and extending and not rotating. I would be concerned about confusion in terms of quantification of movements with the dummy and relating it to certain patterns of injury which is seen in clinical practice.

The second comment I have, is concerning the main emphasis of your work being on hyperextension. Most orthopedic surgeons, I'm sure, would concur that the main body of injuries to the spine recognized in clinical practice, particularly serious, unstable injuries, are flexion injuries or are certainly supposed to be.

Answer: Brian Tanner

We were under the impression from the work that we've read, that because of the limits placed on flexion by the chin into the chest, it was more unusual to see those. However, the work that I had read was based on older research and was not necessarily clinical as much as it was automotive related.

Q: John Melvin, General Motors Research Labs, Biomedical Science

I'd like to add to the gentleman's comments about extension and rotation. Engineers think extension is straight stretching so there is already confusion when engineers and medical people talk together. So, rearward rotation, in fact, is probably less confusing to everybody. As far as the issue of injury mechanisms is concerned, I think the other point concerns some of the pictures that you've shown, possibly the airbag situation. We don't have many of those on the highway yet and so the issue we want to try to understand is injury mechanisms before they occur not after we see them in the clinic. So there is a reason to study these issues of hyperextension. The one concern that I have in your method was the one picture you showed of the head hitting the steering wheel. Basically, the neck in the Hybrid III dummy is S shaped at that point in which the top part of the spine is in extension and the bottom part is in flexion. So, you're going to have a hard time figuring that out with just the motion of the head relative to the torso. This may be a configuration that will give us great difficulty and I would suggest that you continue to measure the moment at the bottom of the neck to understand what is going on.

A: Well, we had considered that and we are aware that that is a problem. What we don't know, at the moment, is how well the Hybrid III actually models what the neck does in that type of situation.

Q: It does go S shaped though, we know that and I think the human spine does do that. What you're doing, of course, is concentrating the motion at one level in the spine and not the entire spine as was determined in the inertial test. One final comment on the ATA device: you mentioned that you had noise from the pendulum. I think you'll find that most of that is noise in the transducer. There is a characteristic 500 Hz signal carried by the ATA velocity transducer at this point.

Question: Guy Nusholtz, Chrysler

Along with the neck moment, another indicator which does not always tell you what type of injuries you're going to have is the head motion. In other words, you can have an extension type of motion with the head, which is really what you're using as a descriptor, and still have other types of injuries. You may have flexion type injuries and so it may also not give you a very good indication of what type injury you might see. Some of the things that John mentioned are some of the reasons that you get S shaped curves in a human or a cadaver subject under those types of loading conditions.